INTERNATIONAL STANDARD

ISO 8178-1

Fourth edition
2020-06

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 1:
Test-bed measurement systems of gaseous and particulate emissions

Moteurs alternatifs à combustion interne — Mesurage des émissions de gaz d'échappement —

Partie 1: Mesurage des émissions de gaz et de particules au banc d'essai

Reference number
ISO 8178-1:2020(E)

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Published in Switzerland

Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement.*

This fourth edition cancels and replaces the third edition (ISO 8178-1:2017), which has been technically revised.

The main changes compared to the previous edition are as follows:

- addition of provision to use alternative systems for ammonia analysis;
- improvement of weighing chamber and analytical balance specifications;
- insertion of general section on measurement instruments;
- revision of particle number measurement system requirements;
- addition concentration and expiration date for analytical gases;
- revision of the annex on carbon flow check;
- addition of the 1980 international gravity formula.

A list of all the parts in the ISO 8178 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is intended for use as a measurement procedure to determine the gaseous and particulate emission levels of reciprocating internal combustion (RIC) engines for non-automotive use. Its purpose is to provide an engine's emissions characteristics which, through use of proper weighting factors and test cycles, can be used as an indication of that engine's emission levels under various applications and for different fuels. The emission results are expressed in units of grams per kilowatt-hour and represent the rate of emissions per unit of work accomplished.

Many of the procedures described in this document are detailed accounts of laboratory methods, since determining an emissions value requires performing a complex set of individual measurements, rather than obtaining a single measured value. Thus, the results obtained depend as much on the process of performing the measurements as they depend on the engine and test method.

Evaluating emissions from non-road engines is more complicated than the same task for on-road engines due to the diversity of non-road applications. For example, on-road applications primarily consist of moving a load from one point to another on a paved roadway. The constraints of the paved roadways, maximum acceptable pavement loads and maximum allowable grades of fuel, narrow the scope of on-road vehicle and engine sizes. Non-road engines and vehicles include a wider range of size, including the engines that power the equipment. Many of the engines are large enough to preclude the application of test equipment and methods that were acceptable for on-road purposes. In cases where the application of dynamometers is not possible, testing at site or under appropriate conditions can be a viable alternative.

In limited instances, the engine can be tested on the test bed in accordance with ISO 8178-2, to test in field conditions. This can only occur with the agreement of the parties involved. It should be recognized that data obtained under these circumstances may not agree completely with previous or future data obtained under the auspices of this document.

For engines used in machinery covered by additional requirements (e.g. occupational health and safety regulations, regulations for power plants), additional test conditions and special evaluation methods may apply.

Where it is not possible to use a test bed or where information is required on the actual emissions produced by an in-service engine, the site test procedures and calculation methods specified in ISO 8178-2 are appropriate.

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 1:
Test-bed measurement systems of gaseous and particulate emissions

1 Scope

This document specifies the measurement methods for gaseous and particulate exhaust emissions from reciprocating internal combustion (RIC) engines on a test bed, necessary for determining one weighted value for each exhaust gas pollutant. Various combinations of engine load and speed reflect different engine applications (see ISO 8178-4).

This document is applicable to RIC engines for mobile, transportable and stationary use, excluding engines for motor vehicles primarily designed for road use. This document can be applied to engines used, for example, for earth-moving machines, generating sets and for other applications.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO 8178-4:2020, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 4: Test cycles for different engine applications*

ASTM F1471–93, *Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air-Filter System*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
accuracy
absolute difference between the reference quantity, y_{ref}, and the arithmetic mean of the ten y_i, y values

Note 1 to entry: See the example of an accuracy calculation in Annex D.

Note 2 to entry: It is recommended that the instrument accuracy be within the specifications in Table 5.

3.2
aqueous condensation
precipitation of water-containing constituents from a gas phase to a liquid phase

Note 1 to entry: Aqueous condensation is a function of humidity, pressure, temperature, and concentrations of other constituents such as sulphuric acid. These parameters vary as a function of engine intake-air humidity, dilution-air humidity, engine air-to-fuel ratio, and fuel composition - including the amount of hydrogen and sulphur in the fuel.

3.3
atmospheric pressure
wet, absolute, atmospheric static pressure

Note 1 to entry: If the atmospheric pressure is measured in a duct, negligible pressure losses shall be ensured between the atmosphere and the measurement location, and changes in the duct's static pressure resulting from the flow shall be accounted for.

3.4
calibration
process of setting a measurement system's response so that its output agrees with a range of reference signals

Note 1 to entry: Contrast with *verification* (3.51).

3.5
calibration gas
purified gas mixture used to calibrate gas analysers

Note 1 to entry: Calibration gases shall meet the specifications of 9.2.1. Note that calibration gases and *span gases* (3.37) are qualitatively the same, but differ in terms of their primary function. Various performance *verification* (3.51) checks for gas analysers and sample handling components might refer to either calibration gases or span gases.

3.6
certification
process of obtaining a certificate of conformity

3.7
conversion efficiency of non-methane cutter
conversion efficiency of NMC
E
efficiency of the conversion of an NMC that is used for the removal of the *non-methane hydrocarbons* (3.21) from the sample gas by oxidizing all hydrocarbons except methane

Note 1 to entry: Ideally, the conversion for methane is 0 % (E_{CH4} = 0) and for the other hydrocarbons represented by ethane is 100 % (E_{C2H6} = 100 %). For the accurate measurement of *NMHC* (3.21), the two efficiencies shall be determined and used for the calculation of the NMHC emission mass flow rate for methane and ethane. Contrast with *penetration fraction* (3.27).

3.8
delay time
difference in time between the change of the component to be measured at the reference point and a system response of 10 % of the final reading (t_{10}) with the sampling *probe* (3.28) being defined as the reference point

Note 1 to entry: For the gaseous components, this is the transport time of the measured component from the sampling probe to the detector (see Figure 1).

3.9
dew point
measure of humidity stated as the equilibrium temperature at which water condenses under a given pressure from moist air with a given absolute humidity

Note 1 to entry: Dew point is specified as a temperature in °C or K, and is valid only for the pressure at which it is measured.

3.10
drift
difference between a zero or *calibration* (3.4) signal and the respective value reported by a measurement instrument immediately after it was used in an emission test

3.11
exhaust aftertreatment system
catalyst, particulate filter, deNO$_x$ system, combined deNO$_x$ particulate filter or any other emission-reducing device that is installed downstream of the engine

Note 1 to entry: This definition excludes exhaust gas recirculation (EGR) and turbochargers, which are considered an integral part of the engine.

3.12
full flow dilution
method of mixing the exhaust gas flow with dilution air prior to separating a fraction of the diluted exhaust gas flow for analysis

3.13
good engineering judgement
judgement made consistent with generally accepted scientific and engineering principles and available relevant information

3.14
HEPA filter
high-efficiency particulate air filter that is rated to achieve a minimum initial particle-removal efficiency of 99,97 % using ASTM F1471–93 or an equivalent standard

3.15
hydrocarbon
HC
hydrocarbon group on which the emission standards are based for each type of fuel and engine

EXAMPLE *THC* (3.47), *NMHC* (3.21) as applicable.

3.16
internationally recognized-traceable standard
international standard which includes but is not limited to the list quoted in Table 1

Table 1 — Internationally recognized-traceable standard

Internationally recognized standard	Where copies of the documents may be purchased
American Society for Testing and Materials (ASTM)	American Society for Testing and Materials, 100 Barr Harbour Dr., P.O. Box C700, West Conshohocken, PA 19428 or www.astm.com
International Organization for Standardization (ISO)	International Organization for Standardization, Case Postale 56, CH-1211 Geneva 20, Switzerland or www.iso.org
National Institute of Standards and Technology (NIST)	Government Printing Office, Washington, DC 20402 or download them free from the Internet at www.nist.gov
Society of Automotive Engineering (SAE)	Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096 or www.sae.org

Table 1 *(continued)*

Internationally recognized standard	Where copies of the documents may be purchased
Institute of Petroleum	Energy Institute, 61 New Cavendish Street, London, W1G 7AR, UK, +44 (0)20 7467 7100 or www.energyinst.org.uk
The National Metrology Institute of Japan (NMIJ)	AIST Tsukuba Headquarters, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan or www.nmij.jp/english/info/
Japanese Industrial Standards (JIS)	Japanese Standards Association (JSA), 4-1-12 Akasaka, Minato-ku, 107-8440, Japan or www.jsa.org.jp/default_english.asp

3.17
isokinetic sampling

process of controlling the flow of the exhaust sample by maintaining the mean sample velocity at the *probe* (3.28) equal to the exhaust stream mean velocity

3.18
linearity

degree to which measured values agree with respective reference values

Note 1 to entry: Linearity is quantified using a linear regression of pairs of measured values and reference values over a range of values expected or observed during testing.

3.19
multiple-filter method

process of using one filter for each of the individual *test cycle* (3.44) modes

Note 1 to entry: The modal weighting factors are accounted for after sampling during the data evaluation phase of the test.

3.20
noise

two times the root-mean-square of the ten standard deviations (that is, $N = 2 \times y_{\mathrm{RMS}(\sigma)}$) when the reference signal is a zero-quantity signal

Note 1 to entry: See the example of a root-mean-square calculation in Annex D. It is recommended that the instrument noise be within the specifications in Table 5.

3.21
non-methane hydrocarbons

NMHC

sum of all *hydrocarbon* (3.15) species except methane

3.22
operator demand

engine operator's input to control engine output

Note 1 to entry: The "operator" may be a person (i.e., manual), or a governor (i.e., automatic) that mechanically or electronically signals an input that demands engine output. Input may be from an accelerator pedal or signal, a throttle-control lever or signal, a fuel lever or signal, a speed lever or signal, or a governor setpoint or signal. Output means engine power, P, which is the product of engine speed, n, and engine torque, T.

3.23
oxides of nitrogen

NO_x

compounds containing only nitrogen and oxygen as measured by the *procedures* (3.29) specified in this document

Note 1 to entry: Oxides of nitrogen are expressed quantitatively as if the NO is in the form of NO_2, such that an effective molar mass is used for all oxides of nitrogen equivalent to that of NO_2.

3.24

partial pressure

pressure, p, attributable to a single gas in a gas mixture

Note 1 to entry: For an ideal gas, the partial pressure divided by the total pressure is equal to the constituent's molar concentration, x.

3.25

partial flow dilution

method of analysing the exhaust gas whereby a part of the total exhaust gas flow is separated and then mixed with an appropriate amount of dilution air prior to reaching the particulate sampling filter

3.26

particulate matter

PM

material collected on a specified filter medium after diluting exhaust with clean filtered air to a temperature and a point as specified in 8.1.4, primarily carbon, condensed *hydrocarbons* (3.15), and sulphates with associated water

3.27

penetration fraction

PF

deviation from ideal functioning of a non-methane cutter

Note 1 to entry: See *conversion efficiency of non-methane cutter* (NMC), E (3.7).

Note 2 to entry: An ideal non-methane cutter would have a methane penetration factor, $f_{\mathrm{PF\ CH4}}$, of 1,000 (that is, a methane conversion efficiency E_{CH4} of 0), and the penetration fraction for all other *hydrocarbons* (3.15) would be 0,000, as represented by $f_{\mathrm{PF\ C2H6}}$ (that is, an ethane conversion efficiency E_{C2H6} of 1). The relationship is: $f_{\mathrm{PF\ CH4}} = 1 - E_{\mathrm{CH4}}$ and $f_{\mathrm{PF\ C2H6}} = 1 - E_{\mathrm{C2H6}}$.

3.28

probe

first section of the transfer tube which transfers the sample to next component in the sampling system

3.29

procedures

all aspects of engine testing, including the equipment specifications, *calibrations* (3.4), calculations and other protocols and specifications needed to measure emissions, unless otherwise specified

3.30

ramped-modal test

test cycle (3.44) with a sequence of steady state engine test modes with defined speed and torque criteria at each mode and defined speed and torque ramps between these modes

3.31

regeneration

event during which emissions levels change while the aftertreatment performance is being restored by design

Note 1 to entry: Two types of regeneration can occur: continuous regeneration (see ISO 8178-4:2020, 5.5.1.2.1) and infrequent (periodic) regeneration (see ISO 8178-4:2020, 5.5.1.2.2);

3.32

repeatability

two times the standard deviation of the ten errors, i.e. $r = 2\sigma_{\varepsilon}$

Note 1 to entry: See the example of a standard-deviation calculation in Annex D. It is recommended that the instrument repeatability be within the specifications shown in Table 5.

3.33
response time

difference in time between the change of the component to be measured at the reference point and a system response of 90 % of the final reading (t_{90}) with the sampling *probe* (3.28) being defined as the reference point, whereby the change of the measured component is at least 60 % full scale (FS) and the devices for gas switching shall be specified to perform the gas switching in less than 0,1 s

Note 1 to entry: The system response time consists of the *delay time* (3.8) to the system and of the *rise time* (3.34) of the system.

3.34
rise time

difference in time of the 10 % and 90 % response of the final reading ($t_{90} - t_{10}$)

3.35
single-filter method

process of using one filter for all *test cycle* (3.44) modes

Note 1 to entry: Modal weighting factors shall be accounted for during the particulate sampling phase of the test cycle by adjusting sample flow rate and/or sampling time. This method dictates that particular attention be given to sampling duration and flow rates.

3.36
span, verb

adjust an instrument so that it gives a proper response to a *calibration* (3.4) standard that represents between 75 % and 100 % of the maximum value in the instrument range or expected range of use

3.37
span gas

purified gas mixture used to *span* (3.36) gas analysers

Note 1 to entry: Span gases shall meet the specifications of 9.2.1. Note that *calibration gases* (3.5) and span gases are qualitatively the same, but differ in terms of their primary function. Various performance *verification* (3.51) checks for gas analysers and sample handling components might refer to either calibration gases or span gases.

3.38
span response

mean response, including *noise* (3.20), to a *span gas* (3.37) during a 30 s time interval

3.39
specific emissions

mass emissions expressed in g/kWh

3.40
stand-alone

having no dependencies

3.41
steady-state

relating to emission tests in which engine speed and load are held at a finite set of nominally constant values

Note 1 to entry: Steady-state tests are either discrete-mode tests or ramped-modal tests (3.30).

3.42
stoichiometric

relating to the particular ratio of air and fuel such that if the fuel were fully oxidized, there would be no remaining fuel or oxygen

3.43
storage medium

particulate filter, sample bag, or any other storage device used for batch sampling

3.44
test cycle
duty cycle
sequence of test points each with a defined speed and torque to be followed by the engine under steady state or transient operating conditions

Note 1 to entry: Duty cycles are specified in ISO 8178-4:2020, Annexes A to C. A single duty cycle may consist of one or more *test intervals* (3.45).

3.45
test interval
duration of time over which brake-specific emissions are determined

Note 1 to entry: In cases where multiple test intervals occur over a *duty cycle* (3.44), the regulation can specify additional calculations that weigh and combine results to arrive at composite values for comparison against the applicable emission limits.

3.46
tolerance
interval in which 95 % of a set of recorded values of a certain quantity lies, with the remaining 5 % of the recorded values deviating from the tolerance interval, using the specified recording frequencies and time intervals to determine if a quantity is within the applicable tolerance

3.47
total hydrocarbon
THC
combined mass of organic compounds measured by the specified procedure for measuring total hydrocarbon

Note 1 to entry: Total hydrocarbon is expressed as a *hydrocarbon* (3.15) with a hydrogen-to-carbon mass ratio of 1,85 (Diesel), 1,93 (petrol (E10)), 2,525 (LPG), 4,0 (NG/biomethane) or 2,74 (ethanol (E85)).

3.48
transformation time
difference in time between the change of the component to be measured at the reference point and a system response of 50 % of the final reading (t_{50}) with the sampling *probe* (3.28) being defined as the reference point

Note 1 to entry: The transformation time is used for the signal alignment of different measurement instruments (see Figure 1).

3.49
transient test cycle
test cycle (3.44) with a sequence of normalized speed and torque values that vary relatively quickly with time

Note 1 to entry: See ISO 8178-4:2020, 7.6.

3.50
updating-recording
frequency at which the analyser provides new, current values

3.51
verification
evaluation of whether or not a measurement system's outputs agree with a range of applied reference signals to within one or more predetermined thresholds for acceptance

Note 1 to entry: Contrast with *calibration* (3.4).

3.52

zero, verb

adjust an instrument, so it gives a *zero response* (3.54) to a zero *calibration* (3.4) standard, such as purified nitrogen or purified air

3.53

zero gas

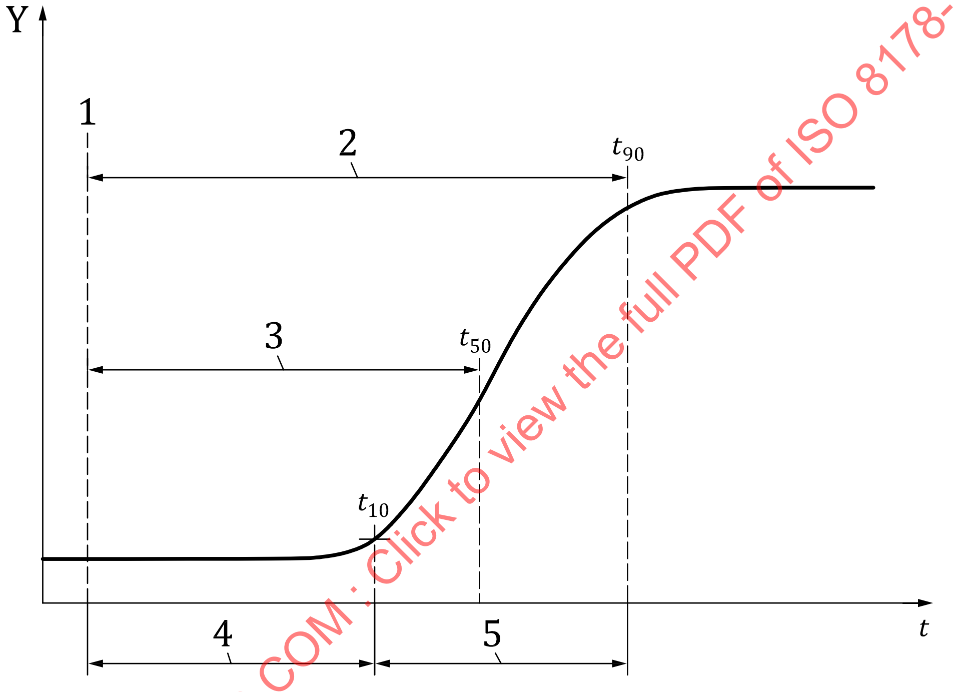
gas that yields a *zero response* (3.54) in an analyser

Note 1 to entry: This may either be purified nitrogen, purified air, a combination of purified air and purified nitrogen.

3.54

zero response

mean response, including *noise* (3.20), to a *zero gas* (3.53) during a 30 s time interval



Key

1	step input time
2	*response time* (3.33)
3	*transformation time* (3.48)
4	*delay time* (3.8)
5	*rise time* (3.34)
t	time
Y	response

Figure 1 — Definitions of system response: delay time, response time, rise time and transformation time

4 Symbols and abbreviated terms

4.1 General symbols

For the purposes of this document, the general symbols given in Table 2 apply.

Table 2 — General symbols

Symbol	Term	Unit
a_0	y intercept of the regression line	—
a_1	Slope of the regression line	—
C_d	CFV discharge coefficient [-]	—
d	Diameter	m
E	Conversion efficiency	%
E_E	Ethane efficiency	%
F	F-test statistics	
f_{PF}	Penetration fraction	%
H_m	Highest expected water vapour concentration	%
m	Mass	kg
m_{ex}	Total mass of diluted exhaust	kg
m_f	Particulate sample mass collected	mg
m_{PM}	Mass of particulate emissions over the test cycle	g
m_{sed}	Mass of diluted exhaust gas passing the dilution tunnel	kg
μ	Dynamic viscosity of exhaust gas	Pa*s
n	Engine speed	min^{-1}
P	Power	kW
p	Pressure	kPa
p_a	Absolute pressure	kPa
p_{total}	Total atmospheric pressure	kPa
q_{ex}	Particle number sample mass flow rate	kg/s
q_{maw}	Intake air mass flow rate on wet basis	kg/s
q_{mdew}	Diluted exhaust gas mass flow rate on wet basis	kg/s
q_{mdw}	Dilution air mass flow rate on wet basis	kg/s
q_{mew}	Exhaust gas mass flow rate on wet basis	kg/s
q_{mf}	Fuel mass flow rate	kg/s
q_{mp}	Sample flow of exhaust gas into partial flow dilution system	kg/s
q_{VCSV}	Air flow rate	m^3/s
q_{sw}	Mass flow rate fed back into dilution tunnel to compensate for particle number sample extraction	kg/s
q_V	Volume flow rate	m^3/s
R	molar gas constant	J/(mol K)
Re	Reynolds number	—
r^2	Coefficient of determination	—
r_d	Dilution ratio	—
r_m	Methanol response factor of the FID	—
r_x	Ratio of the SSV throat to inlet absolute, static pressure	—
r_y	Ratio of the SSV throat diameter, d, to the inlet pipe inner diameter (d_{in})	—
ρ	Density	kg/m^3
S_{EE}	Standard error of estimate of y on x	—
σ	Standard deviation	
T	Temperature	°C
T	Engine torque	Nm
$T_{chiller}$	Absolute chiller temperature	K

Table 2 *(continued)*

Symbol	Term	Unit
T_{dew}	Absolute dew point temperature	K
t	Time	s
t_0	Time between step input and 0 % of final reading	s
t_{10}	Time between step input and 10 % of final reading	s
t_{50}	Time between step input and 50 % of final reading	s
t_{90}	Time between step input and 90 % of final reading	s
V	Volume	m^3
v	Kinematic viscosity	m^2/s
W	Work	kWh
x	Concentration	µmol/mol or %

4.2 Symbols for fuel composition

w_H	hydrogen content of fuel, % mass
w_C	carbon content of fuel, % mass
w_S	sulphur content of fuel, % mass
w_N	nitrogen content of fuel, % mass
w_O	oxygen content of fuel, % mass
α	molar hydrogen-to-carbon ratio (H/C)
β	molar carbon-to-carbon ratio (C/C)
γ	molar sulphur-to-carbon ratio (S/C)
δ	molar nitrogen-to-carbon ratio (N/C)
ε	molar oxygen-to-carbon ratio (O/C)

NOTE The conversion between mass content and molar ratio is given in ISO 8178-4:2020, Formula D.3.

4.3 Symbols and abbreviated terms for the chemical components

ACN	Acetonitrile
C_x	Carbon x equivalent hydrocarbon
C_2H_6	Ethane
C_3H_8	Propane
CH_3OH	Methanol
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide

DNPH	Dinitrophenyl hydrazine
H	Atomic hydrogen
H_2	Molecular hydrogen
H_2O	Water
HCHO	Formaldehyde
He	Helium
N_2	Molecular nitrogen
N_2O	Nitrous oxide
NH_3	Ammonia
NO	Nitric oxide
NO_2	Nitrogen dioxide
O_2	Oxygen
S	Sulphur
SO_2	Sulphur dioxide

4.4 Abbreviated terms

ASTM	American Society for Testing and Materials
CFV	Critical flow venturi
CI	Compression-ignition
CLD	Chemiluminescent detector
CVS	Constant volume sampling
deNOx	NO_x after-treatment system
DAF	Dilution air filter
DC	Damping chamber
DPT	Differential pressure transducer
DT	Dilution tunnel
EDL	Electrode-less discharge lamp
EFC	Electronic flow compensation
EGR	Exhaust gas recirculation
EP	Exhaust pipe
ET	Evaporation tube
FC	Flow controller

FD	Flow divider
FH	Filter holder
FID	Flame ionization detector
FL	Flow meter
FM	Flow measurement device
FS	Full scale
FTIR	Fourier transform infrared (analyser)
GC	Gas chromatograph
HCLD	Heated chemiluminescent detector
HE	Heat exchanger
HEPA	High-efficiency particulate air
HFID	Heated flame ionization detector
HSL	Heated sampling line
HPLC	High-performance liquid chromatograph
IR	Infrared
ISO	International Organization for Standardization
LPG	Liquefied Petroleum Gas
NDIR	Non-dispersive infrared (analyser)
NDUV	Non-dispersive ultraviolet (analyser)
NDUV-RAS	Non-dispersive ultraviolet – resonant absorption spectroscopy
NMC	Non-methane cutter
OT	Outlet tube
PCF	Particle pre-classifier
PDP	Positive displacement pump
PF	Penetration fraction
PFD	Partial flow dilution
PM	Particulate matter
PMD	Paramagnetic detector
PN	Particle number
PNC	Particle number counter
PND	Particle number diluter

PSP	Particulate Sampling probes
PTFE	Polytetrafluoroethylene (commonly known as Teflon®[a])

[a] Teflon® is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

PTS	Particle transfer system
PTT	Particle transfer tube
QCL	Quantum cascade laser (analyser)
RIC	Reciprocating internal combustion (engines)
RTD	Resistive temperature detector
SAE	Society of Automotive Engineers
SSV	Subsonic venturi
TDL	Tunable diode laser (analyser)
UFM	Ultrasonic flow meter
UV	Ultraviolet
V	Valve
VPR	Volatile particle remover

5 General measurement principles

The emission of gaseous and particulate components by the engine submitted for testing shall be measured by the methods described in Clauses 6 to 8. These clauses describe the engine and ambient related measurement systems (Clause 6), the analytical systems for the gaseous emissions (Clause 7) and the particulate sampling systems (Clause 8). The system calibration procedures are described in Clause 9.

Test cycles and emissions calculations are not part of this document. They are included in ISO 8178-4.

Other systems or analysers may be accepted if they yield equivalent results. The determination of system equivalency shall be based on a seven-sample pair (or larger) correlation study between the system under consideration and one of the accepted systems of this document. “Results” refers to the specific cycle weighted emissions value. The correlation testing is to be performed at the same laboratory, test cell, and on the same engine. The tests should be run concurrently. The test cycle to be used shall be the appropriate cycle as found in ISO 8178-4. The equivalency of the sample pair averages shall be determined by *F*-test and *t*-test statistics (see Annex D), with outliers excluded, obtained under the laboratory cell and the engine conditions described above. The systems to be used for correlation testing shall be declared prior to the test and shall be agreed upon by the parties involved.

For introduction of a new system into this document, the determination of equivalency shall be based upon the calculation of repeatability and reproducibility, as described in ISO 5725-2.

5.1 Principle of emission measurement

To measure the brake-specific emissions the engine shall be operated over the test cycles defined in ISO 8178-4, as applicable. The measurement of brake-specific emissions requires the determination of the mass of pollutants in the exhaust and the corresponding engine work.

5.1.1 Mass of constituent

The total mass of each constituent shall be determined over the applicable test cycle by using the following methods:

5.1.1.1 Continuous sampling

In continuous sampling, the constituent's concentration is measured continuously from raw or dilute exhaust. This concentration is multiplied by the continuous (raw or diluted) exhaust flow rate at the emission sampling location to determine the constituent's flow rate. The constituent's emission is continuously summed over the test interval. This sum is the total mass of the emitted constituent.

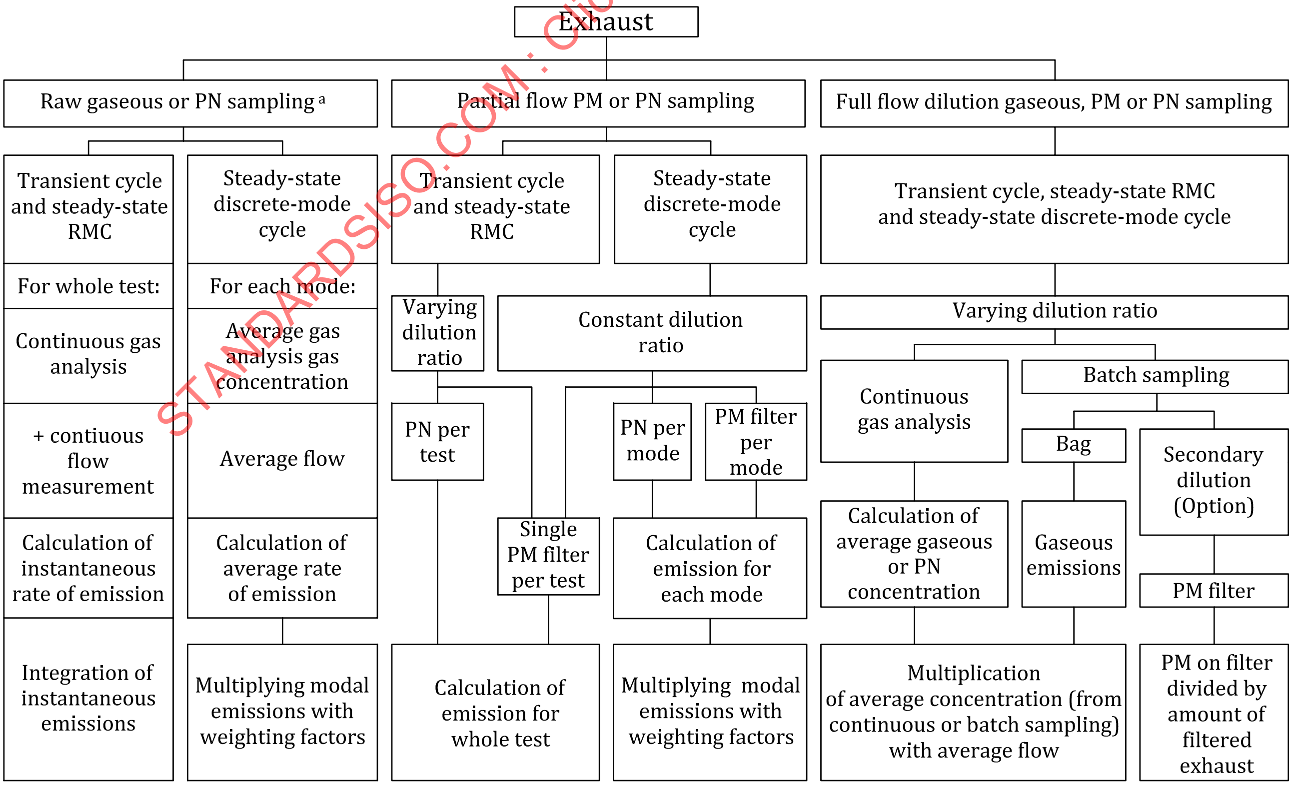
5.1.1.2 Batch sampling

In batch sampling, a sample of raw or dilute exhaust is continuously extracted and stored for later measurement. The extracted sample shall be proportional to the raw or dilute exhaust flow rate. Examples of batch sampling are collecting diluted gaseous emissions in a bag and collecting PM on a filter. In principal the method of emission calculation is done as follows: the batch sampled concentrations are multiplied by the total mass or mass flow (raw or dilute) from which it was extracted during the test cycle. This product is the total mass or mass flow of the emitted constituent. To calculate the PM concentration, the PM deposited onto a filter from proportionally extracted exhaust shall be divided by the amount of filtered exhaust.

5.1.1.3 Combined sampling

Any combination of continuous and batch sampling is permitted (e.g. PM with batch sampling and gaseous emissions with continuous sampling).

Figure 2 illustrates the two aspects of the test procedures for measuring emissions: the equipment with the sampling lines in raw and diluted exhaust gas and the operations requested to calculate the pollutant emissions in steady-state and transient test cycles.



[a] A proportional or constant diluter should be applied for PN measurement (see Figure 14).

NOTE The term "Partial flow PM sampling" includes the partial flow dilution to extract only raw exhaust with constant or varying dilution ratio.

Figure 2 — Test procedures for emission mass measurement

5.2 Exhaust sampling and dilution

5.2.1 General sampling requirements

5.2.1.1 Probe design and construction

A probe is the first fitting in a sampling system. It protrudes into a raw or diluted exhaust stream to extract a sample, such that its inside and outside surfaces are in contact with the exhaust. A sample is transported out of a probe into a transfer tube.

Sample probes shall be made with inside surfaces of stainless steel or, for raw exhaust sampling, with any non-reactive material capable of withstanding raw exhaust temperatures. Sample probes shall be located where constituents are mixed to their mean sample concentration and where interference with other probes is minimised. All probes should remain free from influences of boundary layers, wakes, and eddies – especially near the outlet of a raw-exhaust tailpipe where unintended dilution might occur. Purging or back-flushing of a probe shall not influence another probe during testing. A single probe to extract a sample of more than one constituent may be used as long as the probe meets all the specifications for each constituent.

5.2.1.2 Transfer tubes

Transfer tubes that transport an extracted sample from a probe to an analyser, storage medium, or dilution system shall be minimized in length by locating analysers, storage media, and dilution systems as close to the probes as practical. The number of bends in transfer tubes shall be minimized and that the radius of any unavoidable bend shall be maximized.

5.2.1.3 Sampling methods

For continuous and batch sampling, introduced in 5.1.1, the following conditions apply:

a) when extracting from a constant flow rate, the sample shall also be carried out at a constant flow rate;

b) for batch sampling, when extracting from a varying flow rate, the sample flow rate shall be varied in proportion to the varying flow rate;

c) proportional sampling shall be validated as described in ISO 8178-4:2020, 8.2.1.

Gaseous constituents may be measured raw or diluted whereas PM and PN measurements require dilution.

5.2.2 Gas sampling

5.2.2.1 Sampling probes

Either single-port or multi-port probes are used for sampling gaseous emissions. The probes may be oriented in any direction relative to the raw or diluted exhaust flow. For some probes, the sample temperatures shall be controlled, as follows:

a) for probes that extract NO_x from diluted exhaust, the probe's wall temperature shall be controlled to prevent aqueous condensation;

b) for probes that extract hydrocarbons from the diluted exhaust, the probe wall temperature should be controlled to approximately 191 °C to minimise contamination.

5.2.2.2 Transfer tubes

Transfer tubes with inside surfaces of stainless steel, PTFE, Viton®[1], or any other material that has better properties for emission sampling shall be used. A non-reactive material capable of withstanding exhaust temperatures shall be used. In-line filters may be used if the filter and its housing meet the same temperature requirements as the transfer tubes, as follows:

a) for NO_x transfer tubes upstream of either an NO_2-to-NO converter that meets the specifications of 9.4 or a chiller that meets the specifications of 9.5.9.3 a sample temperature that prevents aqueous condensation shall be maintained;

b) for THC transfer tubes a wall temperature tolerance throughout the entire line of (191 ± 11) °C shall be maintained. If sampled from raw exhaust, an unheated, insulated transfer tube may be connected directly to a probe. The length and insulation of the transfer tube shall be designed to cool the highest expected raw exhaust temperature to no lower than 191 °C, as measured at the transfer tube outlet. For dilute sampling a transition zone between the probe and transfer tube of up to 0,92 m in length is allowed to transition the wall temperature to (191 ± 11) °C.

5.2.2.3 Sample-conditioning components

5.2.2.3.1 Sample dryers

The instrument that is used for removing moisture shall meet the minimum requirements in the following paragraph. The moisture content of 0,8 volume % H_2O is used in ISO 8178-4:2020, Formula (43).

For the highest expected water vapour concentration H_m, the water removal technique shall maintain CLD humidity at ≤5 g water/kg dry air (or about 0,8 volume % H_2O), which is 100 % relative humidity at 3,9 °C and 101,3 kPa. This humidity specification is also equivalent to about 25 % relative humidity at 25 °C and 101,3 kPa. This may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD.

Either type of sample dryer described in this subclause to decrease the effects of water on gaseous emission measurements may be used.

a) If an osmotic-membrane dryer upstream of any gaseous analyser or storage medium is used, it shall meet the temperature specifications in 5.2.2.2. The dew point, T_{dew}, and absolute pressure, p_{total}, downstream of an osmotic-membrane dryer shall be monitored. The amount of water shall be calculated as specified in ISO 8178-4:2020, H.3.2 by using continuously recorded values of T_{dew} and p_{total} or their peak values observed during a test or their alarm set points. Lacking a direct measurement, the nominal p_{total} is given by the dryer's lowest absolute pressure expected during testing.

b) A thermal chiller upstream of a THC measurement system for compression-ignition engines may not be used. If a thermal chiller upstream of an NO_2-to-NO converter or in a sampling system without an NO_2-to-NO converter is used, the chiller shall meet the NO_2 loss-performance check specified in 9.5.9.3. The dew point, T_{dew}, and absolute pressure, p_{total}, downstream of a thermal chiller shall be monitored. The amount of water shall be calculated as specified in ISO 8178-4:2020, Annex H.3.2 by using continuously recorded values of T_{dew} and p_{total} or their peak values observed during a test or their alarm set points. Lacking a direct measurement, the nominal p_{total} is given by the thermal chiller's lowest absolute pressure expected during testing. If it is valid to assume the degree of saturation in the thermal chiller, T_{dew} based on the known chiller efficiency and continuous monitoring of chiller temperature, $T_{chiller}$ may be calculated. If values of $T_{chiller}$ are not

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[1] Viton® is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

continuously recorded, its peak value observed during a test, or its alarm setpoint, may be used as a constant value to determine a constant amount of water according to ISO 8178-4:2020, H.3.2. If it is valid to assume that $T_{chiller}$ is equal to T_{dew}, $T_{chiller}$ may be used in lieu of T_{dew} according to ISO 8178-4:2020, Annex H. If it is valid to assume a constant temperature offset between $T_{chiller}$ and T_{dew}, due to a known and fixed amount of sample reheat between the chiller outlet and the temperature measurement location, this assumed temperature offset value may be factored in into emission calculations. The validity of any assumptions allowed by this subclause shall be shown by engineering analysis or by data.

5.2.2.3.2 Sample pumps

Sample pumps upstream of an analyser or storage medium for any gas shall be used. Sample pumps with inside surfaces of stainless steel, PTFE, or any other material having better properties for emission sampling shall be used. For some sample pumps, temperatures shall be controlled, as follows:

a) if a NO_x sample pump upstream of either an NO_2-to-NO converter that meets the specification of 9.4 or a chiller that meets the specification of 9.5.9.3 is used, it shall be heated to prevent aqueous condensation;

b) if a THC sample pump upstream of a THC analyser or storage medium is used, its inner surfaces shall be heated to a tolerance of (191 ± 11) °C.

5.2.2.3.3 Ammonia scrubbers

Ammonia scrubbers may be used for any or all gaseous sampling system to prevent NH_3 interference, poisoning of NO_2-to-NO converter, and deposits in the sampling system or analysers. Follow the ammonia scrubber manufacturer recommendations or use good engineering in applying ammonia scrubbers.

5.2.2.3.4 Sample storage media

In the case of bag sampling, gas volumes shall be stored in sufficiently clean containers that minimally off-gas or allow permeation of gases. Good engineering judgment shall be used to determine acceptable thresholds of storage media cleanliness and permeation. To clean a container, it may be repeatedly purged and evacuated and may be heated. A flexible container (such as a bag) within a temperature-controlled environment, or a temperature controlled rigid container that is initially evacuated or has a volume that can be displaced, such as a piston and cylinder arrangement, shall be used. Containers meeting the specifications in Table 3 shall be used.

Table 3 — Gaseous batch sampling container materials

CO, CO_2, 0_2, CH_4,C_2H_6,C_3H_8, NO, NO_2[a]	polyvinyl fluoride (PVF)[b], polyvinylidene fluoride[b], polytetrafluoroethylene[c], or stainless steel[c]
THC, NMHC	polytetrafluoroethylen[d] or stainless steel[d]

[a] As long as aqueous condensation in storage container is prevented.

[b] Up to 40 °C.

[c] Up to 202 °C.

[d] At (191 ± 11) °C.

5.2.3 Raw sampling for gaseous emissions

The gaseous emissions sampling probes shall be fitted at least 0,5 m or three times the diameter of the exhaust pipe – whichever is the larger – upstream of the exit of the exhaust gas system but sufficiently close to the engine so as to ensure an exhaust gas temperature of at least 70 °C at the probe.

In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders.

In multi-cylinder engines having distinct groups of manifolds, such as in a "V" engine configuration, instead of taking a sample for the combined flow it is permissible to acquire a sample from each group individually and combine flows and concentrations. Methods may be chosen based on good engineering practice and shall comply with either one of the following requirements:

a) Simultaneous determination of both concentration and exhaust mass flow within each group. The determination may be performed for all groups simultaneously or the test may be repeated for each group sequentially. The emissions shall be calculated for each group from the concentration and exhaust mass flow. The overall result shall be determined by mathematical combination of the emissions from each group.

b) Methods that do not comply with the requirements of section a). In this case it shall be demonstrated to the satisfaction of the parties concerned that the resulting error in the engine emission calculation will not exceed 2 %.

If the composition of the exhaust gas is influenced by any exhaust aftertreatment system, the exhaust sample shall be taken downstream of this device.

For engines with water injection into exhaust system for the purpose of cooling, or noise reduction, the inlet of the probe shall be located so as to avoid ingestion of water, for example a hatted probe may be used.

For spark-ignition engines, sampling may be done in the high-pressure side of the muffler, but as far from the exhaust port as possible. A mixing chamber may be optionally inserted between the muffler outlet and the sample probe. The internal volume of the mixing chamber shall be not less than 10 times the cylinder displacement of the engine under test and should have roughly equal dimensions in height, width and depth. The mixing chamber size should be kept as small as practicable and should be coupled as close as possible to the engine. The exhaust line leaving the mixing chamber should extend at least 610 mm beyond the sample probe location and be of sufficient size to minimize back pressure. The temperature of the inner surface of the mixing chamber shall be maintained above the dew point of the exhaust gases and a minimum temperature of 65 °C is recommended.

5.2.4 Dilute sampling for gaseous emissions

When a full-flow dilution system is used for the determination of the particulates, the gaseous emissions may also be determined in the diluted exhaust gas. The sampling probes shall be close to the particulate sampling probe (PSP) in the dilution tunnel (DT) (see 8.3.3).

For compression-ignition engines, HC and NO_x shall be measured by direct sampling from the dilution tunnel. Alternatively, if the relative temperatures (5.2.2) are met, sampling in a bag and subsequent measurement of the concentration may be used. CO and CO_2 may optionally be determined by direct measurement or by sampling into a bag and subsequent measurement of the concentration in the sampling bag.

For spark-ignition engines and gas-fuelled engines, all components may optionally be measured directly in the dilution tunnel, or by sampling into a bag and subsequent measurement of the concentration in the sampling bag.

5.2.5 Dilution system

Dilution may be accomplished by a full flow or partial flow dilution system. When dilution is applied the exhaust may be diluted with ambient air, purified air, or nitrogen. For gaseous emissions measurement the temperature of the diluent shall be at least 15 °C. For PM sampling the temperature of the diluent is specified in 5.2.5.3 for CVS and 5.2.5.1 for PFD with varying dilution ratio. The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems. De-humidifying the dilution air before entering the dilution system is permitted, if the air humidity is high. The dilution tunnel walls may be heated or insulated as well as the bulk stream tubing downstream of the tunnel to prevent aqueous condensation.

Before a diluent is mixed with exhaust, it may be preconditioned by increasing or decreasing its temperature or humidity. Constituents may be removed from the diluent to reduce their background concentrations. The following provisions apply to removing constituents or accounting for background concentrations:

a) constituent concentrations in the diluent may be measured and compensated for background effects on test results. See ISO 8178-4:2020, Clause 9 and H.6.1 for calculations that compensate for background concentrations;

b) to account for background PM the following options are available:

    1) for removing background PM, the diluent shall be filtered with high-efficiency particulate air (HEPA) filters that have an initial minimum collection efficiency specification of 99,97 % using ASTM F1471–93 or an equivalent standard;

    2) for correcting for background PM without HEPA filtration, the background PM shall not contribute more than 50 % of the net PM collected on the sample filter;

    3) background correction of net PM with HEPA filtration is permitted without restriction;

c) the following changes to the requirements of 5.2, Clause 7 and Clause 8 are permitted for taking a background sample of dilution air and measuring gaseous or particulate pollutants therein:

    1) it shall not be required to use proportional sampling;

    2) unheated sampling systems may be used;

    3) continuous sampling may be used irrespective of the use of batch sampling for diluted emissions;

    4) batch sampling may be used irrespective of the use of continuous sampling for diluted emissions.

5.2.5.1 Partial-flow dilution system

The temperature of the diluents (ambient air, purified air, or nitrogen as quoted in 5.2.5) shall be maintained between 20 °C to 52 °C in close proximity to the entrance into the dilution tunnel.

The partial flow dilution system has to be designed to extract a proportional raw exhaust sample from the engine exhaust stream, thus responding to excursions in the exhaust stream flow rate, and introduce dilution air to this sample to achieve a temperature at the test filter as prescribed by 8.1.4. For this it is essential that the dilution ratio be determined such that the accuracy requirements of 9.8.6.1 are fulfilled.

To ensure that a flow is measured that corresponds to a measured concentration, either aqueous condensation shall be prevented between the sample probe location and the flow meter inlet in the dilution tunnel or aqueous condensation shall be allowed to occur and humidity at the flow meter inlet measured. The PFD system may be heated or insulated to prevent aqueous condensation. Aqueous condensation shall be prevented throughout the dilution tunnel.

The minimum dilution ratio shall be within the range of 5:1 to 7:1 based on the maximum engine exhaust mass flow rate during the test cycle or test interval.

The residence time in the system shall be between 0,5 s and 5 s, as measured from the point of diluent introduction to the filter holder(s).

The partial-flow system shall be designed to extract a raw exhaust sample from the engine exhaust stream, introduce dilution air into this sample and subsequently measure the particulates in the diluted sample. From that it is essential that the dilution ratio be determined very accurately.

Splitting of the exhaust stream and the following dilution process may be done by different dilution system types. For subsequent collection of the particulates, the entire dilute exhaust gas or only a portion of the dilute exhaust gas is passed to the particulate sampling system (see Figures E.1 to E.8). The first method is referred to as total-sampling type, the second method as fractional-sampling type. The calculation of the dilution ratio depends upon the type of system used. Examples of partial-flow dilution system layouts are shown in Annex E.

5.2.5.2 Applicability

PFD may be used to extract a proportional raw exhaust sample for any batch or continuous PM and gaseous emission sampling over any transient duty cycle, any discrete steady-state duty cycle or any ramped-modal steady state duty cycle.

The system may be used also for a previously diluted exhaust where, via a constant dilution ratio, an already proportional flow is diluted (see Figure 8). This is the way of performing secondary dilution from a CVS tunnel to achieve the necessary overall dilution ratio for PM sampling.

The particulate sampling probe shall be fitted close to and upstream of the gaseous probe as defined in 5.2.2.1. See Annex E.

5.2.5.3 Full-flow dilution system

Full-flow dilution; constant-volume sampling (CVS). The full flow of raw exhaust is diluted in a dilution tunnel. Constant flow may be maintained by maintaining the temperature and pressure at the flow meter within the limits. For non-constant flow the flow shall be measured directly to allow for proportional sampling. The system shall be designed as follows (see example in Figure 9):

a) A tunnel with inside surfaces of stainless steel shall be used. The entire dilution tunnel shall be electrically grounded; thin walled and insulated if needed to reduce temperature difference between walls and exhaust gas.

b) The exhaust system backpressure shall not be artificially lowered by the dilution air inlet system. The static pressure at the location where raw exhaust is introduced into the tunnel shall be maintained within ±1,2 kPa of atmospheric pressure.

c) To support mixing the raw exhaust shall be introduced into the tunnel by directing it downstream along the centreline of the tunnel. A fraction of dilution air maybe introduced radially from the tunnel's inner surface to minimize exhaust interaction with the tunnel walls.

d) Diluent. For PM sampling the temperature of the diluents (ambient air, purified air, or nitrogen as quoted in 5.2.5) shall be maintained between 20 °C to 52 °C in close proximity to the entrance into the dilution tunnel.

e) The Reynolds number, *Re*, shall be at least 4 000 for the diluted exhaust stream, where *Re* is based on the inside diameter of the dilution tunnel. *Re* is defined in 9.8.4.2 and in ISO 8178-4:2020, H.8.4. Verification of adequate mixing shall be performed while traversing a sampling probe across the tunnel's diameter, vertically and horizontally. If the analyser response indicates any deviation exceeding ±2 % of the mean measured concentration, the CVS shall be operated at a higher flow rate or a mixing plate or orifice shall be installed to improve mixing.

f) Flow measurement preconditioning. The diluted exhaust may be conditioned before measuring its flow rate, as long as this conditioning takes place downstream of heated HC or PM sample probes, as follows:

   1) flow straighteners, pulsation dampeners, or both of these may be used;

   2) a filter may be used;

   3) a heat exchanger may be used to control the temperature upstream of any flow meter but steps shall be taken to prevent aqueous condensation.

g) Aqueous condensation. To ensure that a flow is measured that corresponds to a measured concentration, either aqueous condensation shall be prevented between the sample probe location and the flow meter inlet in the dilution tunnel or aqueous condensation shall be allowed to occur and humidity at the flow meter inlet measured. The dilution tunnel walls or bulk stream tubing downstream of the tunnel may be heated or insulated to prevent aqueous condensation. Aqueous condensation shall be prevented throughout the dilution tunnel. Certain exhaust components can be reduced or eliminated by the presence of moisture.

   For PM sampling, the already proportional flow coming from CVS goes through secondary dilution (one or more) to achieve the requested overall dilution ratio as shown in Figure 11.

h) The minimum overall dilution ratio shall be within the range of 5:1 to 7:1 and at least 2:1 for the primary dilution stage based on the maximum engine exhaust flow rate during the test cycle or test interval.

i) The overall residence time in the system shall be between 0,5 s and 5 s, as measured from the point of diluent introduction to the filter holder(s).

j) The residence time in the secondary dilution system, if present, shall be at least 0,5 s, as measured from the point of secondary diluent introduction to the filter holder(s).

5.2.6 Dilute sampling for particulate emissions

To determine the mass of the particulates, a particulate sampling system, particulate sampling filters, a microgram balance, and a temperature- and humidity-controlled weighing chamber are required. For particulate sampling, the following two methods may be applied.

The multiple-filter method dictates that one filter is used for each of the individual modes of the test cycle. This method allows more lenient sample procedures but uses more filters.

The single-filter method uses one filter for all modes of the test cycle. Attention shall be paid to sampling times and flows during the sampling phase of the test; however, only one filter will be required for the test cycle.

5.3 Measurement instruments

5.3.1 General

5.3.1.1 Overview

This subclause specifies measurement instruments and associated system requirements related to emission testing. This includes laboratory instruments for measuring engine parameters, ambient conditions, flow-related parameters, and emission concentrations (raw or diluted).

5.3.1.2 Instrument types

Any instrument mentioned in ISO 8178 (all parts) shall be used as described in the standard itself (see Table 7 for measurement quantities provided by these instruments). Whenever an instrument mentioned in this document is used in a way that is not specified, or another instrument is used in its place, the requirements for equivalency provisions shall apply as specified in Clause 5. Where more than one instrument for a particular measurement is specified, one of them will be identified by the type approval or certification authority upon application as the reference for showing that an alternative procedure is equivalent to the specified procedure.

5.3.1.3 Redundant systems

Data from multiple instruments to calculate test results for a single test may be used for all measurement instruments described in this subclause, with prior approval of the type approval or certification authority. Results from all measurements shall be recorded and the raw data shall be retained. This requirement applies whether or not the measurements are actually used in the calculations.

5.3.2 Data recording and control

The test system shall be able to update data, record data and control systems related to operator demand, the dynamometer, sampling equipment, and measurement instruments. Data acquisition and control systems shall be used that can record at the specified minimum frequencies, as shown in Table 4 (this table does not apply to discrete-mode testing).

Table 4 — Data recording and control minimum frequencies

Applicable test protocol subclause in ISO 8178-4:2020	Measured values	Minimum command and control frequency[a]	Minimum recording frequency[b, c]
7.4	Speed and torque during an engine step-map	1 Hz	1 mean value per step
7.4	Speed and torque during an engine sweep-map	5 Hz	1 Hz means
8.6.3	Transient duty cycle reference and feedback speeds and torques	5 Hz	1 Hz means
8.6.2	Steady-state and ramped-modal duty cycle reference and feedback speeds and torques	1 Hz	1 Hz
8.4 8.7	Continuous concentrations of raw analysers	N/A	1 Hz
8.4 8.7	Continuous concentrations of dilute analysers	N/A	1 Hz
8.4 8.7	Batch concentrations of raw or dilute analysers	N/A	1 mean value per test interval
7.4 8.2.1	Diluted exhaust flow rate from a CVS with a heat exchanger upstream of the flow measurement	N/A	1 Hz
7.4 8.2.1	Diluted exhaust flow rate from a CVS without a heat exchanger upstream of the flow measurement	5 Hz	1 Hz means
7.4 8.2.1	Intake-air[d], fuel[d], and raw exhaust flow rate	N/A	1 Hz means

[a] CFVs that are not using active control are exempt from meeting this requirement due to their operating principle.

[b] 1 Hz means are data reported from the instrument at a higher frequency, but recorded as a series of 1 s mean values at a rate of 1 Hz.

[c] For CFVs in a CVS, the minimum recording frequency is 1 Hz. For CFVs used to control sampling from a CFV CVS, the minimum recording frequency is not applicable.

[d] If used for instantaneous raw exhaust flow determination.

[e] This is not applicable to CVS dilution air.

Table 4 *(continued)*

Applicable test protocol subclause in ISO 8178-4:2020	Measured values	Minimum command and control frequency[a]	Minimum recording frequency[b, c]
7.4 8.2.1	Dilution air flow if actively controlled (for example, a partial flow PM sampling system)[e]	5 Hz	1 Hz means
7.4 8.2.1	Sample flow from a CVS with a heat exchanger	1 Hz	1 Hz
7.4 8.2.1	Sample flow from a CVS without a heat exchanger	5 Hz	1 Hz mean

[a] CFVs that are not using active control are exempt from meeting this requirement due to their operating principle.

[b] 1 Hz means are data reported from the instrument at a higher frequency, but recorded as a series of 1 s mean values at a rate of 1 Hz.

[c] For CFVs in a CVS, the minimum recording frequency is 1 Hz. For CFVs used to control sampling from a CFV CVS, the minimum recording frequency is not applicable.

[d] If used for instantaneous raw exhaust flow determination.

[e] This is not applicable to CVS dilution air.

5.3.3 Performance specifications for measurement instruments

5.3.3.1 Overview

The calibration of all measuring instruments shall be traceable to national (international) standards.

The test system as a whole shall meet all the applicable calibrations, verifications, and test-validation criteria specified in Clause 9, including the requirements of the linearity check of 9.1.4 and ISO 8178-4:2020, 8.2. Instruments shall meet the specifications in Table 5 for all ranges to be used for testing. Furthermore, any documentation received from instrument manufacturers showing that instruments meet the specifications in Table 5 shall be kept.

5.3.3.2 Component requirements

Table 5 shows the specifications of transducers of torque, speed, and pressure, sensors of temperature and dew point, and other instruments. The overall system for measuring the given physical and/or chemical quantity shall meet the linearity verification in 9.1.4. For gaseous emissions measurements, analysers may be used, that have compensation algorithms that are functions of other measured gaseous components, and of the fuel properties for the specific engine test. Any compensation algorithm shall only provide offset compensation without affecting any gain (that is, no bias).

Table 5 — Recommended performance specifications for measurement instruments

Measurement Instrument	Measured quantity symbol	Complete System Rise time ($t_{10\text{-}90}$) and Fall time ($t_{90\text{-}10}$)[a]	Recording update frequency	Accuracy[b]	Repeatability[b]	Noise[b]
Engine speed transducer	n	1 s	1 Hz means	2,0 % of pt. or 0,5 % of max.	1,0 % of pt. or 0,25 % of max.	0,05 % of max
Engine torque transducer	T	1 s	1 Hz means	2,0 % of pt. or 1,0 % of max.	1,0 % of pt. or 0,5 % of max	0,05 % of max
Electrical work (active-power meter)	W	1 s	1 Hz means	2,0 % of pt. or 0,5 % of max.	1,0 % of pt. or 0,25 % of max	0,05 % of max
General pressure transducer (not a part of another instrument)	p	5 s	1 Hz	2,0 % of pt. or 1,0 % of max.	1,0 % of pt. or 0,50 % of max.	0,1 % of max
Atmospheric pressure meter used for PM-stabilization and balance environments	p_a	50 s	5 times per hour	50 Pa	25 Pa	5 Pa
General purpose atmospheric pressure meter	p_a	50 s	5 times per hour	250 Pa	100 Pa	50 Pa
Temperature sensor for PM-stabilization and balance environments	T	50 s	0,1 Hz	0,25 K	0,1 K	0,1 K
Other temperature sensor (not a part of another instrument)	T	10 s	0,5 Hz	0,4 % of pt. K or 0,2 % of max. K	0,2 % of pt. K or 0,1 % of max. K	0,1 % of max
Dew point sensor for PM-stabilization and balance environments	T_{dew}	50 s	0,1 Hz	0,25 K	0,1 K	0,02 K
Other dew point sensor	T_{dew}	50 s	0,1 Hz	1 K	0,5 K	0,1 K
Fuel flow meter[c] (Fuel totalizer)		5 s (N/A)	1 Hz (N/A)	2,0 % of pt. or 1,5 % of max.	1,0 % of pt. or 0,75 % of max.	0,5 % of max.
Total diluted exhaust meter (CVS)[c] (With heat exchanger before meter)		1 s (5 s)	1 Hz means (1 Hz)	2,0 % of pt. or 1,5 % of max.	1,0 % of pt. or 0,75 % of max.	1,0 % of max.
Dilution air, inlet air, exhaust, and sample flow meters[c]		1 s	1 Hz means of 5 Hz samples	2,5 % of pt. or 1,5 % of max.	1,25 % of pt. or 0,75 % of max.	1,0 % of max.
Continuous gas analyser	x	5 s	1 Hz	2,0 % of pt. or 2,0 % of meas.	1,0 % of pt. or 1,0 % of meas	1,0 % of max.

[a] The performance specifications identified in the table apply separately for rise time and fall time.

[b] Accuracy, repeatability, and noise are all determined with the same collected data as described in 5.3, and based on absolute values. “pt.” refers to the overall flow-weighted mean value expected at the standard; “max.” refers to the peak value expected at the standard over any test interval, not the maximum of the instrument’s range; “meas” refers to the actual flow-weighted mean measured over any test interval.

[c] The procedure for accuracy, repeatability and noise measurement described in Clause 3 may be modified for flow meters to allow noise to be measured at the lowest calibrated value instead of zero flow rate.

Table 5 *(continued)*

Measurement Instrument	Measured quantity symbol	Complete System Rise time ($t_{10\text{-}90}$) and Fall time ($t_{90\text{-}10}$)[a]	Recording update frequency	Accuracy[b]	Repeatability[b]	Noise[b]
Batch gas analyser	x	—	—	2,0 % of pt. or 2,0 % of meas.	1,0 % of pt. or 1,0 % of meas	1,0 % of max.
Gravimetric PM balance	m_f	—	—	See 8.1.5.2	0,5 µg	—

[a] The performance specifications identified in the table apply separately for rise time and fall time.

[b] Accuracy, repeatability, and noise are all determined with the same collected data as described in 5.3, and based on absolute values. "pt." refers to the overall flow-weighted mean value expected at the standard; "max." refers to the peak value expected at the standard over any test interval, not the maximum of the instrument's range; "meas" refers to the actual flow-weighted mean measured over any test interval.

[c] The procedure for accuracy, repeatability and noise measurement described in Clause 3 may be modified for flow meters to allow noise to be measured at the lowest calibrated value instead of zero flow rate.

6 Engine and ambient related measurement equipment

6.1 Dynamometer specification

An engine dynamometer shall be used that has adequate characteristics to perform the applicable test cycle described in ISO 8178-4:2020 including the ability to meet the appropriate cycle validation criteria, if applicable.

The following are examples of dynamometers that may be used:

a) eddy-current or water-brake dynamometer;

b) alternating-current or direct-current motoring dynamometer;

c) one or more dynamometers.

6.2 Speed and torque sensors

Measurement instruments for work inputs and outputs during engine operation shall meet the specifications in this subclause. Sensors, transducers, and meters should meet the specifications in Table 5. Overall systems for measuring work inputs and outputs shall meet the linearity verifications in 9.1.4.

6.2.1 Shaft work

Work and power shall be calculated from outputs of speed and torque transducers according to 6.2. Overall systems for measuring speed and torque shall meet the calibration and verifications in 9.9 and 9.1.4.

Torque induced by the inertia of accelerating and decelerating components connected to the flywheel, such as the drive shaft and dynamometer rotor, shall be compensated for as needed, based on good engineering judgment.

6.2.2 Speed sensors

A magnetic or optical shaft-position detector with a resolution of at least 60 counts per revolution, in combination with a frequency counter that rejects common-mode noise should be used. Other sensors with an equivalent resolution may be used.

6.2.3 Torque sensors

A variety of methods to determine engine torque may be used. As needed, and based on good engineering judgment, torque induced by the inertia of accelerating and decelerating components connected to the flywheel, such as the drive shaft and dynamometer rotor, shall be compensated for.

When using a load cell, the torque signal shall be transferred to the engine axis and the inertia of the dynamometer shall be considered. The actual engine torque is the torque read on the load cell plus the moment of inertia of the brake multiplied by the angular acceleration. The control system has to perform such a calculation in real time.

Torque shall be measured either by mounting a strain gage or similar instrument in-line between the engine and dynamometer or by measuring torque by mounting a strain gage or similar instrument on a lever arm connected to the dynamometer housing. Torque may be calculated from internal dynamometer signals, such as armature current, as long as this measurement is calibrated as described in 9.9.1.

6.2.4 Engine accessories

The work of engine accessories required to fuel, lubricate, or heat the engine, circulate liquid coolant to the engine, or to operate after-treatment devices shall be accounted for and they shall be installed in accordance with ISO 8178-4:2020, 5.2.

6.3 Pressure transducers, temperature sensors, and dew point sensors

Overall systems for measuring pressure, temperature, and dew point shall meet the calibration in 9.10.

Pressure transducers shall be located in a temperature-controlled environment, or they shall compensate for temperature changes over their expected operating range. Transducer materials shall be compatible with the fluid being measured.

Temperature measurement may be done by systems such as the following:

- thermistors;
- thermocouples;
- resistive temperature detectors (RTDs).

Pressure meters may include:

a) either capacitance-type, quartz crystal, or laser-interferometer transducers for atmospheric pressure or other precision pressure measurements;

b) either strain gage or capacitance-type pressure transducers for other applications;

c) other pressure-measurement instruments, such as manometers.

Dew point meters may include:

a) chilled-surface hygrometers which include chilled mirror detectors and chilled surface acoustic wave (SAW) for PM-stabilization environments;

b) thin-film capacitance sensors, for other applications;

c) other dew point sensors, such as a wet-bulb/dry-bulb psychrometer.

6.4 Flow related measurements

For any type of flow meter, the flow shall be conditioned as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, this may be accomplished by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, straightening fins, orifice plates (or pneumatic pulsation dampeners for the fuel flow meter) to establish a steady and predictable velocity profile upstream of the meter.

6.4.1 Fuel flow

Overall system for measuring fuel flow shall meet the calibration in 9.11.1. In any fuel flow measurement, fuel that bypasses the engine or returns from the engine to the fuel storage tank shall be accounted for.

A fuel flow meter that measures mass directly, such as one that relies on gravimetric or inertial measurement principles should be used. This may involve using a meter with one or more scales for weighing fuel or using a Coriolis meter.

The fuel flow shall be conditioned as needed to prevent any gas bubbles in the fuel from affecting the fuel meter.

6.4.2 Intake air flow

Overall system for measuring intake-air flow shall meet the calibration and linearity verification in 9.11.2 and 9.1.4.

The intake flow meter may include a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer.

Flow conditioning shall be carried out as described in the beginning of 6.4.

6.4.3 Raw exhaust flow

The overall system for measuring raw exhaust flow shall meet the linearity requirements in 9.1.4. Any raw-exhaust meter shall be designed to appropriately compensate for changes in the raw exhaust's thermodynamic, fluid, and compositional states and calibrated according to 9.11.3.

6.4.3.1 Flow meter response time

For the purpose of controlling of a partial flow dilution system to extract a proportional raw exhaust sample, a flow meter response time faster than indicated in Table 5 is required. For partial flow dilution systems with online control, the flow meter response time shall meet the specifications in ISO 8178-4:2020, 8.2.1.2.

Any direct exhaust meter shall be designed to appropriately compensate for changes in the raw exhaust's thermodynamic, fluid, and compositional states. The raw-exhaust flow measurement may involve using an ultrasonic flow meter, a subsonic venturi, an averaging Pitot tube, a hot-wire anemometer, a vortex flowmeter, or other measurement principle. This would generally not involve a laminar flow element or a thermal-mass meter.

Precautions shall be taken to avoid measurement errors which will impact on emission value errors. Such precautions include the careful installation of the device in the engine exhaust system according to the instrument manufacturers' recommendations and to good engineering practice. In particular, engine performance and emissions shall not be affected by the installation of the device.

6.4.3.2 Exhaust cooling

This subclause applies to cooling of the exhaust gas after it leaves the engine. It does not refer to cooling of the exhaust gas that may occur in normal engine operation due to the design of the engine, including, but not limited to, water-cooled exhaust manifolds or turbochargers.

The raw exhaust may be cooled upstream of a raw-exhaust flow meter, as long as all the following provisions are observed:

a) No sampling of PM should be carried out downstream of the cooling.

b) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, no sampling of NMHC should be carried out downstream of the cooling for:

  - compression-ignition engines;
  - 2-stroke spark-ignition engines;
  - 4-stroke spark-ignition engines below 19 kW.

c) The cooling shall not cause aqueous condensation.

6.4.3.3 Application

The measured raw exhaust flow may be used as follows:

a) The actual value of calculated raw exhaust shall be used in the following cases:

  1) Multiply raw exhaust flow rate with continuously sampled concentrations.

  2) Multiply total raw exhaust with batch sampled concentrations.

b) In the following cases, a raw exhaust flow meter signal that does not give the actual value of raw exhaust may be used, as long as it is linearly proportional to the exhaust flow rate's actual calculated value:

  1) For feedback control of a proportional sampling system, such as a partial-flow dilution system.

  2) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

An intake-air flow meter signal may be used instead of the exhaust flow signal in the following cases, as long as it is linearly proportional to the exhaust flow rate's actual calculated value:

a) For feedback control of a proportional sampling system, such as a partial-flow dilution system.

b) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

6.4.4 Indirect exhaust flow

6.4.4.1 Air and fuel measurement method

This involves measurement of the air flow and the fuel flow. Air flowmeters and fuel flowmeters with an accuracy defined in addition to 5.3 shall be used. The instantaneous exhaust gas flow shall be the sum of time-aligned instantaneous air mass flow and fuel mass flow.

6.4.4.2 Fuel flow and carbon balance method

This involves exhaust mass calculation from fuel consumption, fuel composition and exhaust gas concentrations using the carbon balance method. The calculation of the exhaust gas flow shall be in accordance with ISO 8178-4:2020, D.3.2.3.1.

For aftertreatment systems that use urea for NO_x reduction, the method may be used without taking urea consumption into account.

For aftertreatment systems requiring active regeneration, this method does not provide adequate accuracy, unless air- and fuel mass flow of active regeneration system are considered.

6.4.4.3 Tracer measurement method

This involves measurement of the concentration of a tracer gas in the exhaust.

A known amount of an inert gas (e.g. pure helium) shall be injected into the exhaust gas flow as a tracer. The gas is mixed and diluted by the exhaust gas, but shall not react in the exhaust pipe. The concentration of the gas shall then be measured in the exhaust gas sample.

In order to ensure complete mixing of the tracer gas, the exhaust gas sampling probe shall be located at least 1 m or 30 times the diameter of the exhaust pipe – whichever is larger – downstream of the tracer gas injection point. The sampling probe may be located closer to the injection point if complete mixing is verified by comparing the tracer gas concentration with the reference concentration when the tracer gas is injected upstream of the engine.

The tracer gas flow rate shall be set so that the trace gas concentration after mixing becomes lower than the full scale of the trace gas analyser.

The background concentration of the tracer gas c_b may be determined by averaging the background concentration measured immediately before the test run and after the test run. When the background concentration is less than 1 % of the concentration of the tracer gas after mixing (c_mix) at maximum exhaust flow, the background concentration may be neglected.

6.4.4.4 Air flow and air-to-fuel ratio measurement method

This involves exhaust mass calculation from the air flow and the air-to-fuel ratio. The calculation of the exhaust gas flow shall be as follows:

The air flowmeter shall meet the accuracy specifications of Table 5. The CO_2 analyser used shall meet the specifications of 7.3.2, and the total system shall meet the accuracy specifications for the exhaust gas flow.

Optionally, air-to-fuel ratio measurement equipment, such as a zirconia-type sensor, which meets the specifications of 7.3.12 may be used for the measurement of the excess air ratio.

6.4.5 Dilution air and diluted exhaust flow meters

6.4.5.1 Application

Instantaneous diluted exhaust flow rates or total diluted exhaust flow over a test interval shall be determined by using a diluted exhaust flow meter. Raw exhaust flow rates or total raw exhaust flow over a test interval may be calculated from the difference between a diluted exhaust flow meter and a dilution air meter.

6.4.5.2 Component requirements

It is recommended that the diluted exhaust flow meter meets the specifications in Table 5. The overall system for measuring diluted exhaust flow shall meet the calibration and verifications in 9.8. The following meters may be used:

a) For constant-volume sampling (CVS) of the total flow of diluted exhaust, a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement pump (PDP), a subsonic venturi (SSV), or an ultrasonic flow meter (UFM) may be used. Combined with an upstream heat exchanger, either a CFV or a PDP will also function as a passive flow controller by keeping the diluted exhaust temperature constant in a CVS system.

b) For the partial flow dilution (PFD) system the combination of any flow meter with any active flow control system to maintain proportional sampling of exhaust constituents may be used. The total flow of diluted exhaust, or one or more sample flows, or a combination of these flow controls may be controlled to maintain proportional sampling.

For any other dilution system, a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer may be used.

For any type of diluted exhaust flow meter, the flow shall be conditioned as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, this may be accomplished by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

6.4.5.3 Exhaust cooling

This subclause applies to cooling of the exhaust gas after it leaves the engine. It does not refer to cooling of the exhaust gas that may occur in normal engine operation due to the design of the engine, including, but not limited to, water-cooled exhaust manifolds or turbochargers.

Diluted exhaust upstream of a dilute flow meter may be cooled, as long as all the following provisions are observed:

a) PM shall not be sampled downstream of the cooling.

b) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, NMHC shall not be sampled downstream of the cooling.

c) If cooling causes aqueous condensation, NO_x shall not be sampled downstream of the cooling unless the cooler meets the performance verification in 9.5.9.3.

d) If cooling causes aqueous condensation before the flow reaches a flow meter, dew point, T_{dew} and pressure p_{total} shall be measured at the flow meter inlet. These values shall be used in emission calculations according ISO 8178-4:2020, Annex H.

6.4.6 Sample flow meter for batch sampling

A sample flow meter shall be used to determine sample flow rates or total flow sampled into a batch sampling system over a test interval. The difference between two flow meters may be used to calculate sample flow into a dilution tunnel e.g. for partial flow dilution PM measurement and secondary dilution flow PM measurement or total raw exhaust flow over a test interval, e.g. by subtracting dilution air flow from total CVS flow.

Specifications for differential flow measurement to extract a proportional raw exhaust sample is given in 9.8.6.1 and the calibration of differential flow measurement is given in 9.8.6.2.

It is recommended to use a sample flow meter that meets the specifications in Table 5. A sample flow meter may involve a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer. Note that the overall system for measuring sample flow shall meet the linearity verification in 9.1.4. For the special case where CFVs are used for both the diluted exhaust and sample-flow measurements and their upstream pressures and temperatures remain similar during testing, the flow rate of the sample-flow CFV need not be quantified. In this special case, the sample-flow CFV inherently flow-weights the batch sample relative to the diluted exhaust CFV.

Overall system for the sample flow meter shall meet the calibration in 9.11.3.

For any type of sample flow meter, the flow shall be conditioned as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, this may be accomplished by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

6.4.7 Use of gas dividers

A gas divider may be used to blend calibration gases.

If a gas divider is used, it shall blend gases to the specifications of 9.2 and to the concentrations expected during testing. Critical-flow gas dividers, capillary-tube gas dividers, or thermal-mass-meter gas dividers may be used. Viscosity corrections shall be applied as necessary (if not done by gas divider internal software) to appropriately ensure correct gas division. The gas-divider system shall meet the linearity verification in 9.1.4.5. Optionally, the blending device may be checked with an instrument which by nature is linear, e.g. using NO gas with a CLD. The span value of the instrument shall be adjusted with the span gas directly connected to the instrument. The gas divider shall be checked at the settings used and the nominal value shall be compared to the measured concentration of the instrument.

7 Determination of the gaseous components

7.1 General specifications

The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components.

7.2 Gas drying

Exhaust gases may be measured wet or dry. A gas-drying device, if used, shall have a minimal effect on the composition of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.

Sample dryers shall meet the specifications in 5.2.2.3.1.

7.3 Analysers

7.3.1 General

7.3.2 to 7.3.12 define the measurement principles to be used. A detailed description of the measurement systems is given in 7.4. The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearizing circuits is permitted.

7.3.2 Carbon monoxide (CO) and carbon dioxide (CO_2) analysis

A Non-dispersive infrared (NDIR) analyser shall be used to measure CO and CO_2 concentrations in raw or diluted exhaust for either batch or continuous sampling.

The NDIR-based system shall meet the calibration and verifications in 9.5.8.

7.3.3 Oxygen (O_2) analysis

A paramagnetic detection (PMD) analyser shall be used to measure O_2 concentration in raw or diluted exhaust for batch or continuous sampling.

7.3.4 Hydrocarbon (HC) analysis

7.3.4.1 General

A heated flame-ionization detector (HFID) analyser shall be used to measure hydrocarbon concentrations in raw or diluted exhaust for either batch or continuous sampling. Hydrocarbon concentrations shall be determined on a carbon number basis of one, C_1. Methane and non-methane hydrocarbon values shall be determined as described in 7.3.5.1. Heated FID analysers shall maintain all surfaces that are exposed to emissions at a temperature of (191 ± 11) °C.

For methanol-fuelled engines, the temperature requirements of 7.3.11.3 apply. Optionally, for gas-fuelled engines and for the dilute testing of spark-ignition engines, the hydrocarbon analyser may be of the non-heated flame ionization detector (FID) type.

7.3.4.2 FID fuel and burner air

FID fuel and burner air shall meet the specifications of 9.2. The FID fuel and burner air shall not mix before entering the FID analyser to ensure that the FID analyser operates with a diffusion flame and not a premixed flame.

7.3.5 Non-methane hydrocarbon (NMHC) analysis

7.3.5.1 General

FID analysers measure total hydrocarbons (THC). To determine non-methane hydrocarbons (NMHC), methane, CH_4, shall be quantified either with a non-methane cutter and a FID analyser as described in 7.3.5.3, or with a gas chromatograph as described in 7.3.5.2. For a FID analyser used to determine NMHC, its response factor to CH_4, $f_{\mathrm{RF\ CH4}}$, shall be determined as described in 9.5. NMHC-related calculations are described in ISO 8178-4:2020, Clause 9 and Annex H.

For engines operated only on Diesel fuel, it is allowed to assume that 2 % of measured total hydrocarbons is methane, instead of measuring methane.

7.3.5.2 Gas chromatographic (GC) method

A gas chromatograph may be used to measure CH_4 concentrations of diluted exhaust for batch sampling. While also a non-methane cutter may be used to measure CH_4, as described in 7.3.5.3 a reference procedure based on a gas chromatograph shall be used for comparison with any proposed alternate measurement procedure in Annex B.

7.3.5.3 Non-methane cutter (NMC) method

A non-methane cutter may be used to measure CH_4 with a FID analyser. A non-methane cutter oxidizes all non-methane hydrocarbons to CO_2 and H_2O. A non-methane cutter may be used for raw or diluted exhaust for batch or continuous sampling.

Non-methane-cutter performance shall be determined as described in 9.5.7 and the results shall be used to calculate NMHC emission in ISO 8178-4:2020, Clause 9 and Annex H.

The non-methane cutter shall be configured with a bypass line for the verification described in 9.5.7.

A non-methane cutter may be optimised to maximize the penetration of CH_4 and the oxidation of all other hydrocarbons. A sample may be humidified and a sample may be diluted with purified air or oxygen (O_2) upstream of non-methane cutter to optimize its performance. Any sample humidification and dilution shall be accounted for in emission calculations.

7.3.6 Oxides of nitrogen (NO_x) analysis

The following measurement instruments are specified for NO_x measurement and either instrument may be used provided it meets the criteria specified in 7.3.6.1 to 7.3.6.4, respectively. The chemiluminescent detector shall be used as the reference procedure for comparison with any proposed alternate measurement procedure in Annex B.

7.3.6.1 CLD

The CLD-based system shall meet the quench verification in 9.5.9.1. A heated or unheated CLD may be used, and a CLD that operates at atmospheric pressure or under a vacuum may be used.

An internal or external NO_2-to-NO converter that meets the verification in 9.4 shall be placed upstream of the CLD, while the converter shall be configured with a bypass to facilitate this verification.

A heated CLD may be used to improve CLD response time.

7.3.6.1.1 Humidity effects

All CLD temperatures shall be maintained to prevent aqueous condensation. To remove humidity from a sample upstream of a CLD, one of the following configurations shall be used:

a) a CLD connected downstream of any dryer or chiller that is downstream of an NO_2-to-NO converter that meets the verification in 9.4;

b) a CLD connected downstream of any dryer or thermal chiller that meets the verification in 9.5.9.3.

7.3.6.2 NDUV

A non-dispersive ultraviolet (NDUV) analyser is used to measure NO_x concentration in raw or diluted exhaust for batch or continuous sampling.

If the NDUV analyser measures only NO, an internal or external NO_2-to-NO converter that meets the verification in 9.4 shall be placed upstream of the NDUV analyser. The converter shall be configured with a bypass to facilitate this verification.

7.3.6.2.1 Humidity effects

All NDUV temperatures shall be maintained to prevent aqueous condensation. To remove humidity from a sample upstream of a NDUV, one of the following configurations shall be used:

a) a NDUV connected downstream of any dryer or chiller that is downstream of an NO_2-to-NO converter that meets the verification in 9.4;

b) a NDUV connected downstream of any dryer or thermal chiller that meets the verification in 9.5.9.3.

7.3.6.3 NDUV-RAS

Alternatively, an NDUV-RAS (non-dispersive ultraviolet - resonant absorption spectroscopy) analyser may be used to measure oxides of nitrogen without the use of a NO_2-to-NO converter. The NDUV-RAS analyser determines NO concentrations by means of gas filter and interference filter correlation measurements of light, emitted by a gas-filled electrode-less discharge lamp (EDL) in a very narrow spectral range NO_2 concentration is determined with the same set-up by means of interference filter correlation measurements. If the NDUV-RAS analyser measures only NO, a NO_2-to-NO converter with bypass capability shall be placed upstream of the analyser.

In order to prevent humidity effects, either the temperature of all gas feeding parts the NDUV-RAS analyser shall be maintained above the exhaust's dew point, or a dryer or gas cooler shall be connected upstream of the analyser. If the NDUV-RAS analyser is connected to a NO_2-to-NO converter, the gas cooler shall be connected between the converter and the analyser in order to avoid NO_2 losses in the cooler.

7.3.6.4 Laser infrared analyser

A laser infrared analyser may be used for NO_x measurement in accordance with the instrument supplier's instructions. The NO_x concentration may be determined by summing NO and NO_2 concentrations, since conventional engines and aftertreatment systems do not emit significant amounts of other NO_x species. The temperature of the sample line shall be maintained to prevent water condensation.

Examples of infrared laser analysers are pulsed-mode high resolution narrow band mid-infrared analysers such as analysers using QCL (quantum cascade laser).

7.3.7 Sulphur dioxide (SO_2) analysis

7.3.7.1 Calculation

The SO_2 emission shall be calculated from the sulphur content of the fuel used, since experience has shown that using the direct measurement method for SO_2 does not give more precise results:

$$q_{m\mathrm{SO2}} = q_{m\mathrm{f}} \times w_{\mathrm{GAM}} \times 20 \tag{1}$$

where

$q_{m\mathrm{SO2}}$	is SO_2 mass flow rate, kg/s;
$q_{m\mathrm{f}}$	is fuel mass flow rate, kg/s;
w_{GAM}	is S content of fuel, % mass.

NOTE The application of the calculation method for SO_2 assumes a 100 % sulphur conversion and is limited to engines without aftertreatment systems.

7.3.7.2 Measurement

If an aftertreatment system is used, SO_2 shall be measured in accordance with the instructions of the instrument suppliers with prior agreement of the parties involved. Condensation shall be avoided.

Sulphur dioxide analysers shall be of the FTIR, NDIR or NDUV types.

7.3.8 Ammonia (NH_3) analysis

A FTIR (Fourier transform infrared) analyser, NDUV or laser infrared analyser may be used in accordance with 7.4.3.

7.3.9 Dinitrogen oxide (N_2O) analysis

An FTIR analyser, an NDIR (non-dispersive infrared) analyser, laser infrared analyser or NDUV analyser may be used in accordance with the instrument supplier's instructions.

7.3.10 Formaldehyde (HCHO) analysis

Formaldehyde shall be determined by passing an exhaust sample, preferably from the diluted exhaust gas, through an impinger containing an acetonitrile (ACN) solution of DNPH reagent or through a silica cartridge coated with 2.4-DNPH. The sample collected shall be analysed by a high-performance liquid chromatograph (HPLC) using UV detection at 365 nm.

Optionally, an FTIR or NDIR analyser may be used in accordance with the instrument supplier's instructions.

7.3.11 Methanol (CH_3OH) analysis

7.3.11.1 General

An FTIR analyser may be used in accordance with the instrument supplier's instructions. Since the technology has not been fully demonstrated for exhaust measurements, prior agreement of the parties involved is required.

7.3.11.2 Gas chromatographic (GC) method

Methanol shall be determined by passing an exhaust sample through an impinger containing de-ionized water. The sample shall be analysed by a GC with FID.

7.3.11.3 HFID method

The HFID calibrated on propane shall be operated at 112 °C ± 10 °C. The methanol response factor shall be determined at several concentrations in the range of concentrations in the sample, according to 9.5.10.

To fulfil the accuracy specified above, the sensor shall be calibrated as specified by the instrument manufacturer.

7.3.12 Air-to-fuel measurement

The air-to-fuel measurement equipment used to determine the exhaust gas flow as specified in 6.4.4.4 shall be a wide range air-to-fuel ratio sensor or lambda sensor of zirconia type.

The sensor shall be mounted directly on the exhaust pipe where the exhaust gas temperature is high enough to eliminate water condensation.

The accuracy of the sensor with incorporated electronics shall be as follows:

— ±3 % of reading for $\lambda < 2$;

— ±5 % of reading for $2 \leq \lambda < 5$;

— ±10 % of reading for $5 \leq \lambda$.

To fulfil the accuracy specified above, the sensor shall be calibrated as specified by the instrument manufacturer.

7.4 Measurement system

7.4.1 General

7.4.2 to 7.4.6 and Figure 3 to Figure 6 contain detailed descriptions of the typical sampling and analysing systems. Since various configurations can produce equivalent results, exact conformance with these figures is not required. However, conformance with the basic requirements such as sampling line heating is mandatory. Additional components such as instruments, valves, solenoids, pumps, filters and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on certain systems may be excluded if their exclusion is based upon good engineering judgement.

7.4.2 Analytical system

An analytical system for the determination of the gaseous emissions in the raw or diluted exhaust gas is described, based on the use of the analyzers in 7.3. Annex F provides examples of the exhaust gas analysis system.

For the raw exhaust gas (see Figure F.1 as an example), the sample for all components may be taken with one sampling probe or with two sampling probes located in close proximity and internally split to the different analysers. Care shall be taken that no condensation of exhaust components (including water and sulphuric acid) occurs at any point of the analytical system.

For the diluted exhaust gas (see Figure F.2 as an example), the sample for the hydrocarbons shall be taken with a sampling probe other than that used with the sample for the other components, unless a common sample pump is used for all analysers and the sample line system design reflects good engineering practice. Care shall be taken that no condensation of exhaust components (including water and sulphuric acid) occurs at any point of the analytical system.

All components in the sampling gas path shall be maintained at the temperatures specified for the respective systems.

7.4.3 Ammonia analysis

Four measurement principles are specified for ammonia (NH_3) measurement and either principle may be used provided it meets the criteria specified in 7.4.3.1 to 7.4.3.2, respectively. Gas dryers shall not be permitted for NH_3 measurement.

7.4.3.1 In-situ measurement devices

7.4.3.1.1 Laser infrared analyser

7.4.3.1.1.1 Measurement principle

The Laser Infrared Analyser employs the single line spectroscopy principle. The NH_3 absorption line is chosen in the near infrared spectral range and scanned by a single-mode laser.

7.4.3.1.1.2 Installation

The analyser shall be installed either directly in the exhaust pipe (in-situ) or within an analyser cabinet using extractive sampling in accordance with the instrument manufacturers' instructions. If installed in an analyser cabinet, the sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated to a temperature between 110 °C and 202 °C in order to minimize NH_3 losses and sampling artefacts. In addition, the sampling line shall be as short as practically possible.

Influence from exhaust temperature and pressure, installation environment and vibrations on the measurement shall be minimized, or compensation techniques be used.

If applicable, sheath air used in conjunction with in-situ measurement for protection of the instrument, shall not affect the concentration of any exhaust component measured downstream of the device, or sampling of other exhaust components shall be made upstream of the device.

7.4.3.1.1.3 Cross interference

The spectral resolution of the laser shall be within 0,5 cm^{-1} in order to minimize cross interference from other gases present in the exhaust gas.

7.4.3.2 Extractive measurement devices

7.4.3.2.1 Fourier transform infrared (FTIR) analyser

7.4.3.2.1.1 Measurement principle

The FTIR employs the broad waveband infrared spectroscopy principle. It allows simultaneous measurement of exhaust components whose standardized spectra are available in the instrument. The absorption spectrum (intensity/wavelength) is calculated from the measured interferogram (intensity/time) by means of the Fourier transform method.

7.4.3.2.1.2 Installation and sampling

The FTIR shall be installed in accordance with the instrument manufacturer's instructions. The NH_3 wavelength shall be selected for evaluation. The sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated a temperature between 110 °C and 202 °C in order to minimize NH_3 losses and sampling artefacts. In addition, the sampling line shall be as short as practically possible.

7.4.3.2.1.3 Cross interference

The spectral resolution of the NH_3 wavelength shall be within 0,5 cm^{-1} in order to minimize cross interference from other gases present in the exhaust gas.

7.4.3.2.2 NDUV

7.4.3.2.2.1 Measurement principle

The method is called Non Dispersive Ultra Violet Resonance Absorption Spectroscopy (NDUV), since the method is based on purely physical principle, no auxiliary gases or equipment is necessary.

The main element of the photometer is an electrode-less discharge lamp. It produces a sharply structured radiation in the ultraviolet range, enabling the measurement of several components such as NH_3.

The photometric system has a dual beam in time design set up to produce a measuring and a reference beam by filter correlation technique.

In order to achieve a high stability of the measuring signal the dual beam in time design is combined with a dual beam in space design. The detector signals processing fosters an almost negligible amount of zero point drift rate.

In the calibration mode of the analyser a sealed-off quartz cell is tilted into the beam path to obtain an exact calibration value, since any reflection and absorption losses of the cell windows are cancelled out. Since the gas filling of the cell is very stable, this calibration method leads to long term stability of the photometer.

7.4.3.2.2.2 Installation

The analyser shall be installed within an analyser cabinet using extractive sampling in accordance with the instrument manufacturer’s instructions.

The analyser location shall be capable of supporting the weight specified by the manufacturer.

If installed in an analyser cabinet, the sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated a temperature between 110 °C and 202 °C.

In addition, the sampling line shall be as short as possible.

Influence from exhaust temperature and pressure, installation environment and vibrations on the measurement shall be minimized.

The gas analyser shall be protected from cold, heat, temperature variations, and strong air currents, accumulation of dust, corrosive atmosphere and vibrations.

Adequate air circulation shall be provided to avoid heat build-up.

The complete surface shall be used to dissipate the heat losses.

7.4.3.2.2.3 Cross sensitivity

An appropriate spectral range needs to be chosen in order to minimize cross interferences of accompanying gases. Typical components causing cross sensitivities on the NH_3 measurement are SO_2, NO_2 and NO.

Additionally, further methods can be applied to reduce the cross sensitivities.

a) usage of interference filters;

b) cross sensitivity compensation by measuring cross sensitivity components and using the measurement signal for compensation.

7.4.3.2.3 Laser Infrared Analyser

7.4.3.2.3.1 Measurement principle

An infrared laser such as a tunable diode laser (TDL) or a quantum cascade laser (QCL) can emit coherent light in the near-infrared region or in mid-infrared region respectively where nitrogen compounds including NH_3 have strong absorption. This laser optics can give a pulsed-mode high resolution narrow band near-infrared or mid-infrared spectrum. Therefore, laser infrared analysers can reduce interference caused by the spectral overlap of co-existing gases in engine exhaust.

7.4.3.2.3.2 Installation and sampling

The laser infrared analyser shall be installed in accordance with the instrument manufacturer's instructions. The sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated to a temperature between 110 °C and 202 °C in order to minimize NH_3 losses and sampling artefacts. In addition, the sampling line shall be as short as practically possible.

7.4.3.2.3.3 Interference verification for NH_3 laser infrared analysers (Cross interference)

a) Scope and frequency:

If NH_3 is measured using laser infrared analyser, the amount of interference shall be verified after initial analyser installation and after major maintenance.

b) Measurement principles for interference verification:

Interference gases can positively interfere with certain laser infrared analyser by causing a response similar to NH_3. If the analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyser interference verification.

Good engineering judgment shall be used to determine interference gases for laser infrared analyser. Note that interference species, with the exception of H_2O, are dependent on the NH_3 infrared absorption band chosen by the instrument manufacturer. For each analyser determine the NH_3 infrared absorption band. For each NH_3 infrared absorption band, good engineering judgment shall be used to determine interference gases to use in the verification.

7.4.3.3 Emissions test procedure

7.4.3.3.1 Checking the analysers

Prior to the emissions test, the analyser range shall be selected. Emission analysers with automatic or manual range switching shall be permitted. During the test cycle, the range of the analysers shall not be switched.

Zero and span response shall be determined, if the provisions of 7.4.3.3.4.2 do not apply for the instrument. For the span response, a NH_3 gas that meets the specifications of 7.4.3.4.2.7 shall be used. The use of reference cells that contain NH_3 span gas is permitted.

7.4.3.3.2 Collection of emission relevant data

At the start of the test sequence, the NH_3 data collection shall be started, simultaneously. The NH_3 concentration shall be measured continuously and stored with at least 1 Hz on a computer system.

7.4.3.3.3 Operations after test

At the completion of the test, sampling shall continue until system response times have elapsed. Determination of analyser's drift in accordance with 7.4.3.3.4.1 shall only be required if the information in 7.4.3.3.4.2 is not available.

7.4.3.3.4 Analyser drift

7.4.3.3.4.1 Drift verification

As soon as practical but no later than 30 minutes after the test cycle is complete or during the soak period, the zero and span responses of the analyser shall be determined. The difference between the pre-test and post-test results shall be less than 2 % of full scale.

7.4.3.3.4.2 Drift verification exemption

Determination of analyser drift is not required in the following situations:

a) if the zero and span drift specified by the instrument manufacturer in 7.4.3.4.2.3 and 7.4.3.4.2.4 meets the requirements of 7.4.3.3.4.1;

b) the time interval for zero and span drift specified by the instrument manufacturer in points 7.4.3.4.2.3 and 7.4.3.4.2.4 exceeds the duration of the test.

7.4.3.4 Analyser specification and verification

7.4.3.4.1 Linearity requirements

The analyser shall comply with the linearity requirements specified in Table 7. The linearity verification in accordance with 9.1.4 shall be performed at least at the minimum frequency set out in Table 6. With the prior approval of the Type Approval Authority, less than 10 reference points are permitted, if an equivalent accuracy can be demonstrated.

For the linearity verification, a NH_3 gas that meets the specifications of 7.4.3.4.2.7 shall be used. The use of reference cells that contain NH_3 span gas shall be permitted.

Instruments, whose signals are used for compensation algorithms, shall meet the linearity requirements specified in Table 7. Linearity verification shall be done as required by internal audit procedures or by the instrument manufacturer. The implementation of a quality management system, such as in accordance with ISO 9000, is advised.

7.4.3.4.2 Analyser specifications

The analyser shall have a measuring range and response time appropriate for the accuracy required to measure the concentration of NH_3 under transient and steady state conditions.

7.4.3.4.2.1 Minimum detection limit

The analyser shall have a minimum detection limit of <2 µmol/mol under all conditions of testing.

7.4.3.4.2.2 Accuracy

The accuracy, defined as the deviation of the analyser reading from the reference value, shall not exceed ±3 % of the reading or ±2 µmol/mol, whichever is larger.

7.4.3.4.2.3 Zero drift

The drift of the zero response and the related time interval shall be specified by the instrument manufacturer.

7.4.3.4.2.4 Span drift

The drift of the span response and the related time interval shall be specified by the instrument manufacturer.

7.4.3.4.2.5 System response time

The system response time shall be ≤20 s.

7.4.3.4.2.6 Rise time

The rise time of the analyser shall be ≤5 s.

7.4.3.4.2.7 NH_3 calibration gas

A gas mixture with the following chemical composition shall be available.

NH3 and purified nitrogen.

The true concentration of the calibration gas shall be within ±3 % of the nominal value. The concentration of NH_3 shall be given on a volume basis (volume per cent or µmol/mol).

The expiration date of the calibration gases stated by the manufacturer shall be recorded.

7.4.3.4.2.8 Interference verification procedure

The interference verification shall be performed as follows:

a) The NH_3 analyser shall be started, operated, zeroed, and spanned as it would be before an emission test.

b) A humidified interference test gas shall be created by bubbling a multi component span gas through distilled H_2O in a sealed vessel. If the sample is not passed through a dryer, the vessel temperature shall be controlled to generate an H_2O level at least as high as the maximum expected during emission testing. Interference span gas concentrations shall be used at least as high as the maximum expected during testing.

c) The humidified interference test gas shall be introduced into the sample system.

d) The water mole fraction, x_{H2O}, of the humidified interference test gas shall be measured; as close as possible to the inlet of the analyser. For example, dew point, T_{dew}, and absolute pressure, p_{total}, shall be measured to calculate x_{H2O}.

e) Good engineering judgment shall be used to prevent condensation in the transfer lines, fittings, or valves from the point where x_{H2O} is measured to the analyser.

f) Time shall be allowed for the analyser response to stabilize.

g) While the analyser measures the sample's concentration, its output shall be recorded for 30 s. The arithmetic mean of this data shall be calculated.

h) The analyser meets the interference verification if the result of g) meets the tolerance in this subclause.

i) Interference procedures for individual interference gases may also run separately. If the interference gas levels used are higher than the maximum levels expected during testing, each observed interference value may be scaled down by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. Separate interference concentrations of H_2O (down to 0,025 mol/mol H_2O content) that are lower than the maximum levels expected during testing may be run, but the observed H_2O interference shall be scaled up by multiplying the observed interference by the ratio of the maximum expected H_2O concentration value to the actual value used during this procedure. The sum of the scaled interference values shall meet the tolerance for combined interference as specified in j).

j) The analyser shall have combined interference within ±2 ppm or as specified by the parties involved.

7.4.3.4.2.9 Alternative systems

Other systems or analysers may be approved by the approval authority, if it is found that they yield equivalent results in accordance with Clause 5. In this case, "results" in that point shall refer to the mean NH_3 concentration calculated for the applicable cycle.

7.4.4 Methane analysis

The methane (CH_4) analysis can be done in two ways.

7.4.4.1 Gas chromatographic (GC) method (Figure 3)

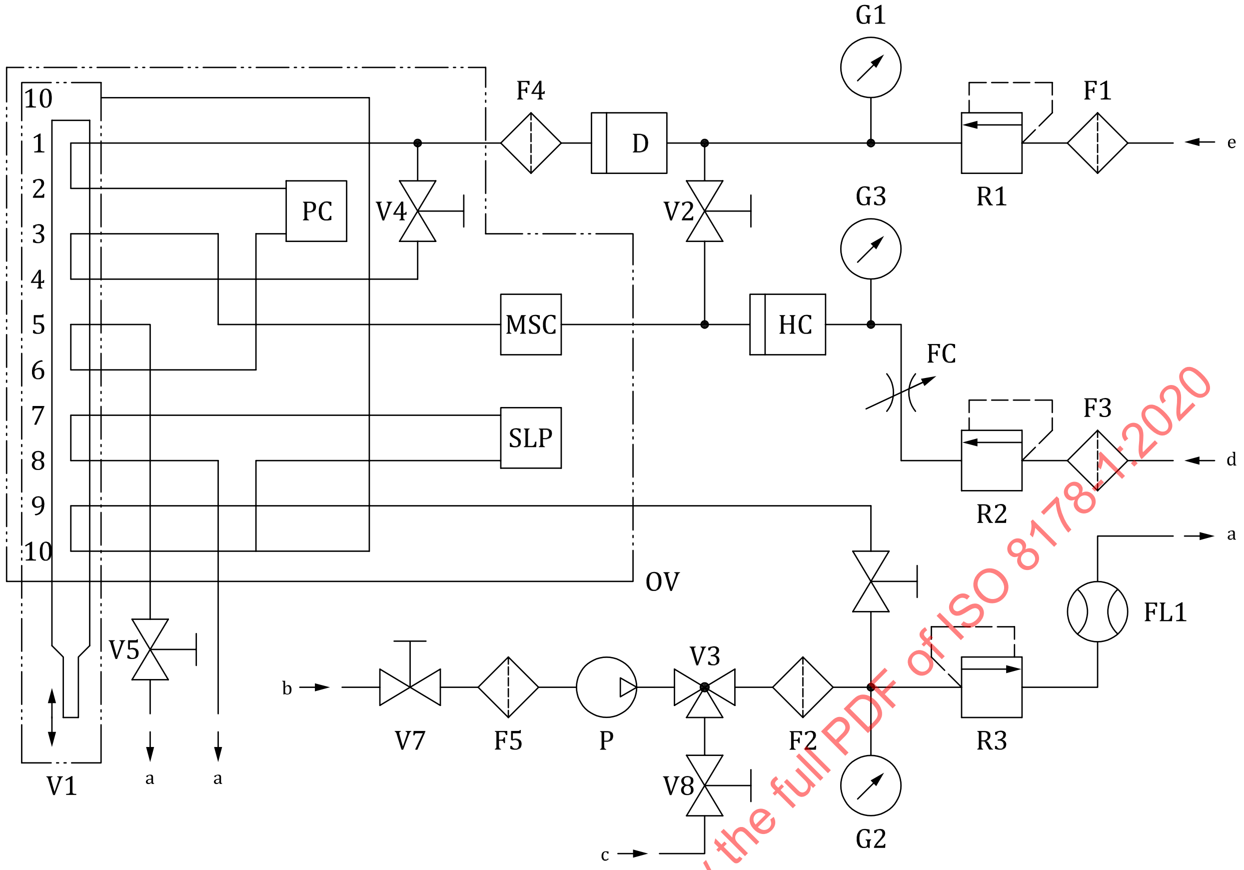
For details of this method see SAE J 1151.

When using the GC method, a small measured volume of a sample is injected into an analytical column through which it is swept by an inert carrier gas. The column separates various components according to their boiling points so that they elute from the column at different times. Then they pass through a detector which gives an electrical signal that depends on their concentration. This is not a continuous analysis technique.

For CH_4 an automated GC with a FID shall be used. The exhaust gas is sampled into a sampling bag from which a part is taken and injected into the GC. The sample is separated into two parts (CH_4/air/CO and NMHC/CO_2/H_2O) on the Porapak column. The molecular sieve column separates CH_4 from the air and CO before passing it to the FID. A complete cycle from injection of one sample to injection of a second one can be made in 30 s.

Figure 3 shows an example of GC assembled to routinely determine CH_4.

Other GC methods can also be used based on good engineering judgement.



a Vent.

b Sample.

c Span gas.

d Air inlet.

e Fuel inlet.

Figure 3 — Flow diagram for methane analysis (GC method)

Components of Figure 3

PC — Porapak column

Porapak N, 180/300 µm (50/80 mesh), 610 mm length × 2,16 mm inner diameter shall be used and conditioned for at least 12 h at 150 °C with carrier gas prior to initial use. The column length, column inner diameter and the temperature may change according to the column material.

MSC — molecular sieve column

Type 13X, 250/350 µm (45/60 mesh), 1 220 mm length × 2,16 mm inner diameter shall be used and conditioned for at least 12 h at 150 °C with carrier gas prior to initial use. The column length, column inner diameter and the temperature may change according to the column material.

OV — oven

To maintain columns and valves at a stable temperature for analyser operation, and to condition the columns at 150 °C. The temperature may change according to the column material, length and inner diameter.

SLP — sample loop

A sufficient length of stainless steel tubing to obtain approximately 1 cm^3 volume.

P — pump

To bring the sample to the gas chromatograph.

D — dryer

To remove water and other contaminants which might be present in the carrier gas; contains a molecular sieve.

HC — flame ionization detector (FID)

To measure the concentration of methane.

V1 — sample injection valve

To inject the sample. It shall be low dead volume, gas-tight, and heatable to 150 °C.

V3 — selector valve

To select span gas, sample or no flow.

V2, V4, V5, V6, V7, V8 — needle valves

To set the flows in the system.

R1, R2, R3 — pressure regulators

To control the flow rate of the fuel (i.e. carrier gas), the sample and the air, respectively.

FC — flow capillary

To control the rate of air flow to the FID.

G1, G2, G3 — pressure gauges

To monitor the flow of the fuel (i.e. carrier gas), the sample and the air, respectively.

F1, F2, F3, F4, F5 — filters

Sintered metal filters to prevent grit from entering the pump or the instrument.

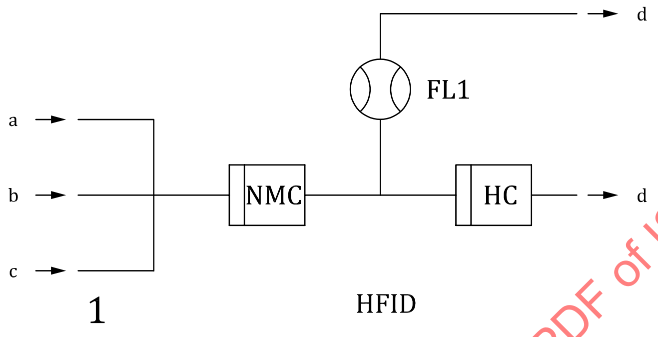
FL1 — flowmeter

To measure the sample bypass flow rate.

7.4.4.2 Non-methane cutter (NMC) method

The cutter oxidizes all hydrocarbons except CH_4 to CO_2 and H_2O, so that by passing the sample through the NMC only CH_4 is detected by the HFID. The usual HC sampling train (see 7.4.2) shall be equipped with a flow diverter system with which the flow can be alternatively passed through or around the cutter. During non-methane testing, both values shall be observed on the FID and recorded.

The cutter shall be optimized by adjusting its temperature to achieve the conversion efficiencies.



Key

1	HSL
a	Zero.
b	Span gas.
c	Sample.
d	Vent.

Figure 4 — Flow diagram for methane analysis (NMC method)

Components of Figure 4

NMC — non-methane cutter

To oxidize all hydrocarbons except methane.

HC

Heated flame ionization detector (HFID) to measure the HC and CH_4 concentrations. The temperature shall be kept at (191 ± 11) °C.

FL1 — flowmeter

To measure the sample bypass flow rate.

7.4.4.3 FTIR (Fourier transform infrared) method

With the agreement of the parties involved, FTIR may be used to determine NMHC. Just as in other sections where the use of the FTIR has been mentioned, care shall be taken to follow manufacturer's guidelines and the Table 7 requirements for linearity verifications.

It is recommended that SAE J 2992 for FTIR providing detailed procedures for the setup and operation of the FTIR for automotive emissions applications be used as a guide to follow good engineering practice. The use of the FTIR is generally beneficial when running natural gas engines and dual fueled engines especially when the ratio of CH_4 to THC is greater than 50 %. In this case, the use of the FID THC and NMC difference method can lead to larger potential NMHC measurement errors with the errors increasing with higher CH_4 to THC ratios.

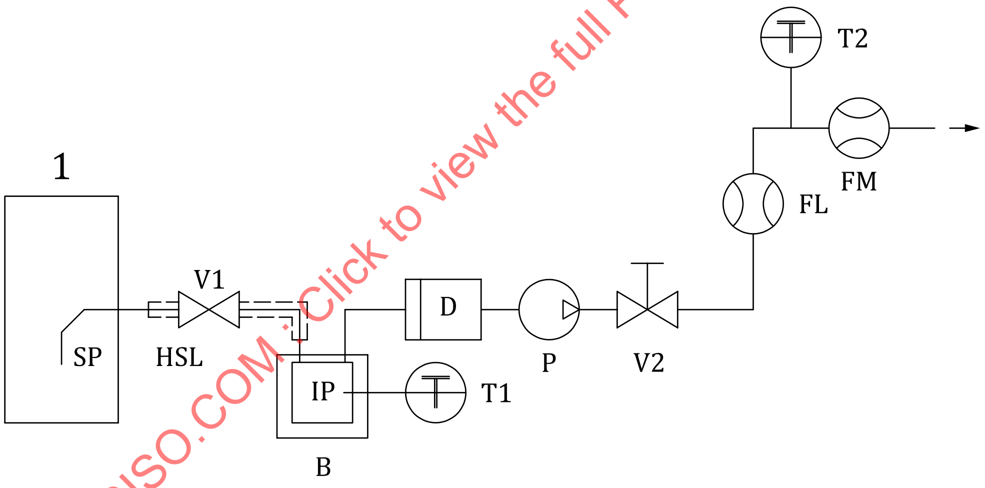
The FTIR should be used to measure individual components of NMHC that are present in the exhaust which would then be added to provide the quantity NMHC emissions. Typically, the following NMHC components are observed: Ethane, Propane, Butane, Pentane and C_6 and higher hydrocarbon components.

7.4.5 Methanol analysis

Among the methanol analysis methods described in 7.3.11, this subclause describes the gas chromatographic (GC) method (see Figure 5).

The exhaust sample is passed through two ice-cooled impingers placed in series containing de-ionized water. Sampling time and flow rate should be such that a CH_3OH concentration of at least 1 mg/l be reached in the primary impinger. The CH_3OH concentration in the second impinger shall not be more than 10 % of the total amount collected. These requirements do not apply to background measurements.

A sample from the impingers is injected into the GC, preferably not later than 24 h after the test in accordance with established gas chromatographic procedures. If it is not possible to perform the analysis within 24 h, the sample should be stored in a dark cold environment of 4 °C to 10 °C until analysis. CH_3OH is separated from the other components and detected with an FID. The GC is calibrated with known amounts of CH_3OH standards.



Key

1 exhaust pipe or dilution tunnel

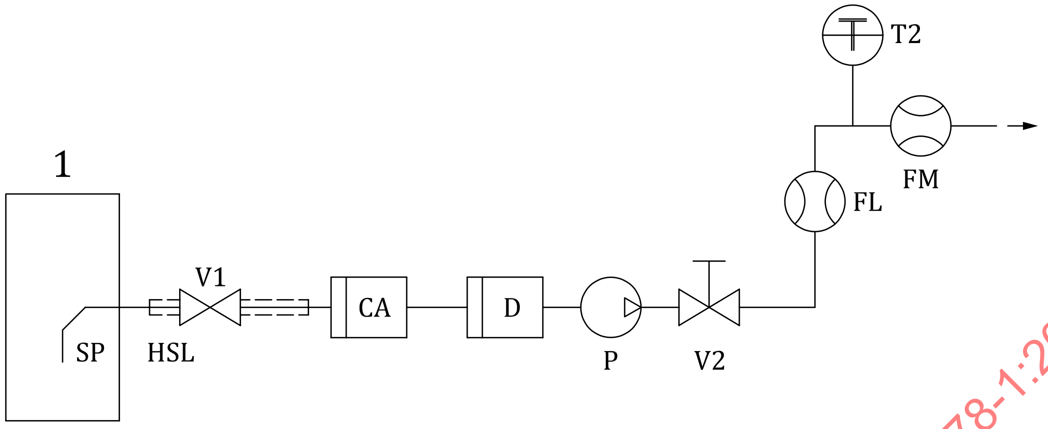
Figure 5 — Flow diagram for methanol analysis

7.4.6 Formaldehyde analysis

In the HPLC (high-performance liquid chromatograph), a small measured volume of the sample is injected into an analytical column through which it is swept by an inert liquid under pressure. Separation, elution and detection of the components follow the same general rules as with the GC. Like the GC, it is not a continuous analysis technique.

The exhaust sample is passed through two ice-cooled impingers placed in series containing an ACN solution of DNPH reagent or through a silica cartridge coated with 2.4-DNPH. The HCHO concentration in the collectors should be at least 1 mg/l.

A sample from the collector is injected into the HPLC preferably not later than 24 h after the test. If it is not possible to perform the analysis within 24 h, the sample should be stored in a dark, cold environment of 4 °C to 10 °C until analysis. HCHO is separated from the other carbonyl components by gradient elution (Figure 6) and detected with a UV detector at 365 nm. The HPLC is calibrated with standards of CHO-DNPH derivatives.



Key

1 exhaust pipe or dilution tunnel

Figure 6 — Flow diagram for formaldehyde analysis

Components of Figure 5 and Figure 6

SP — sampling probe

For the raw exhaust gas, a stainless steel, straight, closed-end, multi-hole probe should be used. The inside diameter shall not be greater than the inside diameter of the sampling line. The wall thickness of the probe shall not be greater than 1 mm. There shall be a minimum of three holes in three different radial planes sized to sample approximately the same flow. The probe shall extend across at least 80 % of the diameter of the exhaust pipe. The probe shall be fitted close to the HC/CO/NO_x/CO_2/O_2 sampling probe as defined in 5.2.3.

For the diluted exhaust gas, the probe shall be in the same plane of the dilution tunnel DT (see Figure 9) as the HC, CO/NO_x/CO_2 and particulate sampling probes, but sufficiently distant from other probes and the tunnel wall to be free from the influence of any wakes or eddies.

HSL — heated sampling line

The temperature of the HSL shall be between the maximum dew point of the mixture and 121 °C. Heating of the HSL may be omitted, provided the sample collection system (IP) be close coupled to the SP, thereby preventing loss of sample due to cooling and resulting condensation in the HSL.

IP — impinger (optional for formaldehyde)

To collect the methanol or formaldehyde in the sample. The impingers should be cooled with ice or a refrigeration unit.

CA — cartridge collector (formaldehyde only; optional)

To collect the formaldehyde in the sample.

B — cooling bath

To cool the impingers.

D — dryer (optional)

To remove water from the sample.

P — sampling pump

V1 — solenoid valve

To direct the sample to the collection system.

V2 — needle valve

To regulate the sample flow through the collection system.

T1 — temperature sensor

To monitor the temperature of the cooling bath.

T2 — temperature sensor (optional)

To monitor the temperature of the sample.

FL — flow meter (optional)

To measure the sample flow rate through the collection system.

FM — flow measurement device

Gas meter or other flow instrumentation to measure the flow through the collection system during the sampling period.

8 Particulate determination

8.1 Particulate mass

8.1.1 Particulate Sampling probes (PSP)

PM probes with a single opening at the end shall be used. PM probes shall be oriented to face directly upstream.

The PM probe may be shielded with a hat that conforms with the requirements in Figure 7. In this case the pre-classifier described in 8.1.3 shall not be used.

Dimensions in millimetres

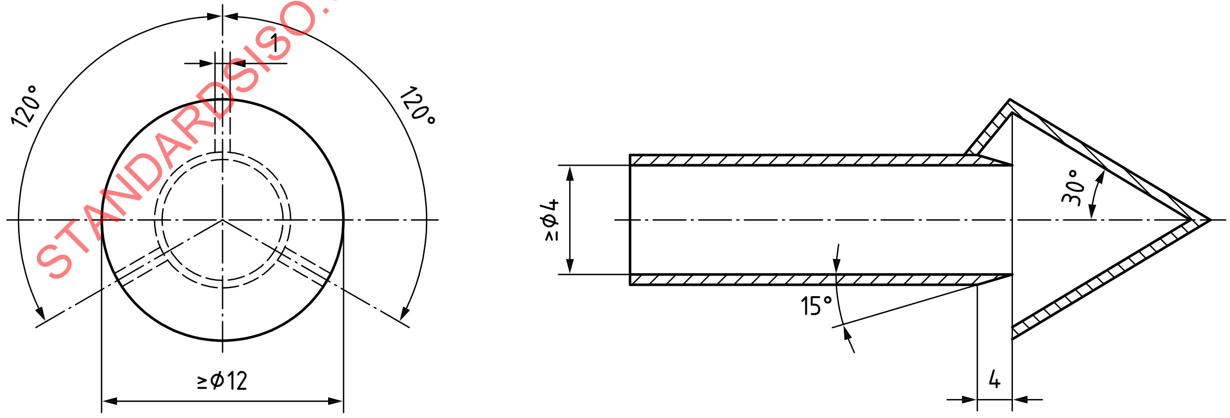


Figure 7 — Scheme of a sampling probe with a hat-shaped pre-classifier

8.1.2 Transfer tubes

Insulated or heated transfer tubes or a heated enclosure should be used to minimize temperature differences between transfer tubes and exhaust constituents. Transfer tubes that are inert with respect to PM and are electrically conductive on the inside surfaces shall be used. PM transfer tubes should be as short as possible and made of stainless steel; any material other than stainless steel will be required to meet the same sampling performance as stainless steel, such as electrical conductivity. The inside surface of PM transfer tubes shall be electrically grounded.

8.1.3 Pre-classifier

The use of a PM pre-classifier to remove large-diameter particles is permitted that is installed in the dilution system directly before the filter holder. Only one pre-classifier is permitted. If a hat shaped probe is used (see Figure 7), the use of a pre-classifier is prohibited. The PM pre-classifier may be either an inertial impactor or a cyclonic separator. It shall be constructed of stainless steel. The pre-classifier shall be rated to remove at least 50 % of PM at an aerodynamic diameter of 10 µm and no more than 1 % of PM at an aerodynamic diameter of 1 µm over the range of flow rates for which it is used. The pre-classifier outlet may be configured with a means of bypassing any PM sample filter so that the pre-classifier flow can be stabilized before starting a test. PM sample filter shall be located within 75 cm downstream of the pre-classifier's exit.

8.1.4 Particulate sampling filters

The diluted exhaust shall be sampled by a filter that meets the requirements of 8.1.4.1 to 8.1.4.4 during the test sequence.

8.1.4.1 Filter specification

All filter types shall have collection efficiency of at least 99,7 %. The sample filter manufacturer's measurements reflected in their product ratings may be used to show this requirement. The filter material shall be either:

a) Fluorocarbon (PTFE) coated glass fibre; or

b) Fluorocarbon (PTFE) membrane.

If the expected net PM mass on the filter exceeds 400 µg on a 46,50 mm filter, a filter with a minimum initial collection efficiency of 98 % may be used.

8.1.4.2 Filter size

The nominal filter size shall be 46,50 mm ± 0,6 mm diameter (at least 37 mm stain diameter). Larger diameter filters are acceptable with prior agreement between the parties involved. Proportionality between filter and stain area is recommended.

8.1.4.3 Dilution and temperature control of PM samples

PM samples shall be diluted at least once upstream of transfer tubes in case of a CVS system and downstream in case of PFD system (see 8.1.2 relating to transfer tubes). Sample temperature is to be controlled to a (47 ± 5) °C tolerance, as measured anywhere within 200 mm upstream or 200 mm downstream of the PM storage media. The PM sample is intended to be heated or cooled primarily by dilution conditions as specified in 5.2.5.

8.1.4.4 Filter face velocity

A filter face velocity shall be between 0,90 and 1,00 m/s with less than 5 % of the recorded flow values exceeding this range. If the total PM mass exceeds 400 µg on a 46,50 mm filter, the filter face velocity may be reduced. The face velocity shall be measured as the volumetric flow rate of the sample at the pressure upstream of the filter and temperature of the filter face, divided by the filter's exposed area. The exhaust stack or CVS tunnel pressure shall be used for the upstream pressure if the pressure drop through the PM sampler up to the filter is less than 2 kPa.

8.1.5 Weighing chamber and analytical balance specifications

This subclause describes the two environments required to stabilize and weigh PM for gravimetric analysis: the PM stabilization environment, where filters are stored before weighing; and the weighing environment, where the balance is located. The two environments may share a common space. Both the stabilization and the weighing environments shall be kept free of ambient contaminants, such as dust, aerosols, or semi-volatile material that could contaminate PM samples.

The cleanliness of the PM-stabilization environment using reference filters shall be verified, as described in 9.6.3.4.

The temperature of the chamber (or room) in which the particulate filters are conditioned and weighed shall be maintained to within (295 ± 1) K (22 °C ± 1 °C) during all filter conditioning and weighing. The humidity shall be maintained to a dew point of (282,5 ± 1) K (9,5 °C ± 1 °C) and a relative humidity of 45 % ± 8 %. If the stabilization and weighing environments are separate, the stabilization environment shall be maintained at a tolerance of (295 ± 3) K (22 °C ± 3 °C).

8.1.5.1 Verification of ambient conditions

When using measurement instruments that meet the specifications in 5.3 the following ambient conditions shall be verified:

a) Dew point and ambient temperature shall be recorded. These values shall be used to determine if the stabilization and weighing environments have remained within the tolerances specified in 8.1.5 for at least 60 min before weighing filters.

b) Atmospheric pressure shall be continuously recorded within the weighing environment. An acceptable alternative is to use a barometer that measures atmospheric pressure outside the weighing environment, as long as it can be ensured that the atmospheric pressure at the balance is always at the balance within ±100 Pa of the shared atmospheric pressure. That means to record the most recent atmospheric pressure shall be provided when each PM sample is weighed. This value shall be used to calculate the PM buoyancy correction in 9.6.3.5.

8.1.5.2 Analytical balance

A balance shall be used to weigh net PM collected on sample filter media.

The minimum requirement on the balance resolution shall be equal or lower than the repeatability of 0,5 microgram recommended in Table 5.

If the balance uses internal calibration weights for routine spanning and linearity verifications, the calibration weights shall meet the following specifications:

PM balance calibration weights that are certified as international and/or national recognized standards-traceable within 0,1 % uncertainty shall be used. Calibration weights may be certified by any calibration lab that maintains international and/or national recognized standards-traceability. It shall be made sure that the lowest calibration weight has no greater than ten times the mass of an unused PM-sample medium. The calibration report shall also state the density of the weights.

The balance shall be configured for optimum settling time and stability at its location.

The balance shall be installed as follows:

a) installed on a vibration-isolation platform to isolate it from external noise and vibration;

b) shielded from convective airflow with a static-dissipating draft shield that is electrically grounded.

8.1.5.3 Elimination of static electricity effects

Static electric charge shall be minimized in the balance environment, as follows:

a) The balance is electrically grounded.

b) Stainless steel tweezers shall be used if PM samples shall be handled manually.

c) Tweezers shall be grounded with a grounding strap, or a grounding strap shall be provided for the operator such that the grounding strap shares a common ground with the balance.

d) A static-electricity neutralizer shall be provided that is electrically grounded in common with the balance to remove static charge from PM samples.

8.1.5.4 Additional specifications for particulate measurement

All parts of the dilution system and the sampling system from the exhaust pipe up to the filter holder, which are in contact with raw and diluted exhaust gas, shall be designed to minimize deposition or alteration of the particulates. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

8.2 Particle number

8.2.1 Sampling

Particle number emissions shall be measured by continuous sampling from either the raw exhaust gas, as described in 5.2.3 for gaseous emissions, but using a pre-classifier according to 8.1.3, and with a diluter, a partial flow or a full flow dilution system as described in 8.3.2 and 8.3.3.

8.2.1.1 Diluent filtration

Diluent used for both the primary and, where applicable, secondary dilution of the exhaust in the dilution system shall be passed through filters meeting the High-Efficiency Particulate Air (HEPA) filter requirements defined in 8.3.2 and 8.3.3. The diluent may optionally be charcoal scrubbed before being passed to the HEPA filter to reduce and stabilize the hydrocarbon concentrations in the diluent. It is recommended that an additional coarse particle filter is situated before the HEPA filter and after the charcoal scrubber, if used.

8.2.2 Compensating for particle number sample flow — Full flow dilution systems

To compensate for the mass flow extracted from the dilution system for particle number sampling the extracted mass flow (filtered) shall be returned to the dilution system. Alternatively, the total mass flow in the dilution system may be mathematically corrected for the particle number sample flow extracted. Where the total mass flow extracted from the dilution system for the sum of particle number sampling and particulate mass sampling is less than 0,5 % of the total dilute exhaust gas flow in the dilution tunnel (q_{mdew}) this correction, or flow return, may be neglected.

8.2.3 Compensating for particle number sample flow — Partial flow dilution systems

For partial flow dilution systems the mass flow extracted from the dilution system for particle number sampling shall be accounted for in controlling the proportionality of sampling. This shall be achieved either by feeding the particle number sample flow back into the dilution system upstream of the flow measuring device or by mathematical correction as outlined in this subclause. In the case of total sampling type partial flow dilution systems, the mass flow extracted for particle number sampling shall also be corrected in the particulate mass calculation as outlined in 8.2.4.

The instantaneous exhaust gas flow rate into the dilution system (q_{mp}), used for controlling the proportionality of sampling, shall be corrected according to one of the following methods:

a) In the case where the extracted particle number sample flow is discarded, Formula (25) in 9.8.6.1 shall be replaced by the following:

$$q_{mp} = q_{m\mathrm{dew}} - q_{m\mathrm{dw}} + q_{\mathrm{ex}} \tag{2}$$

where

q_{mp} is sample flow of exhaust gas into partial flow dilution system, kg/s;

$q_{m\mathrm{dew}}$ is diluted exhaust mass flow rate through the PM filter, kg/s;

$q_{m\mathrm{dw}}$ is dilution air mass flow rate, kg/s;

q_{ex} is particle number sample mass flow rate, kg/s.

The q_{ex} signal sent to the partial flow system controller shall be accurate to within 0,1 % of $q_{m\mathrm{dew}}$ at all times and should be sent with frequency of at least 1 Hz.

b) In the case where the extracted particle number sample flow is fully or partially discarded, but an equivalent flow is fed back to the dilution system upstream of the flow measurement device, Formula (25) in 9.8.6.1 shall be replaced by the following:

$$q_{mp} = q_{m\mathrm{dew}} - q_{m\mathrm{dw}} + q_{\mathrm{ex}} - q_{\mathrm{sw}} \tag{3}$$

where

q_{mp} is sample flow of exhaust gas into partial flow dilution system, kg/s;

$q_{m\mathrm{dew}}$ is diluted exhaust mass flow rate through the PM filter, kg/s;

$q_{m\mathrm{dw}}$ is dilution air mass flow rate, kg/s;

q_{ex} is particle number sample mass flow rate, kg/s;

q_{sw} is mass flow rate fed back into dilution tunnel to compensate for particle number sample extraction, kg/s.

The difference between q_{ex} and q_{sw} sent to the partial flow system controller shall be accurate to within 0,1 % of $q_{m\mathrm{dew}}$ at all times. The signal (or signals) should be sent with frequency of at least 1 Hz.

8.2.4 Correction of PM measurement

When a particle number sample flow is extracted from a total sampling partial flow dilution system, the mass of particulates (m_{PM}) calculated in ISO 8178-4:2020, 9.2.4.1 shall be corrected as follows to account for the flow extracted. This correction is required even where filtered extracted flow is fed back into the partial flow dilution systems.

$$m_{\mathrm{PM,corr}} = m_{\mathrm{PM}} \times m_{\mathrm{sed}}/(m_{\mathrm{sed}} - m_{\mathrm{ex}}) \tag{4}$$

where

$m_{\mathrm{PM,corr}}$ is mass of particulates corrected for extraction of particle number sample flow, g/test;

m_{PM} is mass of particulates determined according to ISO 8178-4:2020, 9.2.4.1, g/test;

m_{sed} is total mass of diluted exhaust gas passing through the dilution tunnel, kg;

m_{ex} is total mass of diluted exhaust gas extracted from the dilution tunnel for particle number sampling, kg.

Other mathematical treatments of the sample flow apportionment strategy within the control system of the partial flow sampling systems are acceptable as long as they provide equivalent results specific to brake specific particulate matter (PM) and particle number (PN).

8.2.5 Proportionality of partial flow dilution sampling

For particle number measurement, exhaust mass flow rate, determined according to any of the methods described in ISO 8178-4:2020, Clause 9 is used for controlling the partial flow dilution system to take a sample proportional to the exhaust mass flow rate. The quality of proportionality shall be checked by applying a regression analysis between sample and exhaust flow in accordance with ISO 8178-4:2020, 8.2.1.2.

8.3 Particulate dilution sampling system equipment

8.3.1 General

Figure 8, Figure 9, Annex E and Figure E.1 to Figure E.8 contain detailed descriptions of the customary dilution and sampling systems. Since various configurations can produce equivalent results, exact conformance with these figures is not required. Additional components such as instruments, valves, solenoids, pumps and switches may be used to provide additional information and coordinate the functions of the component systems. Other components, which are not needed to maintain the accuracy on certain systems, may be excluded if their exclusion is based upon good engineering judgment.

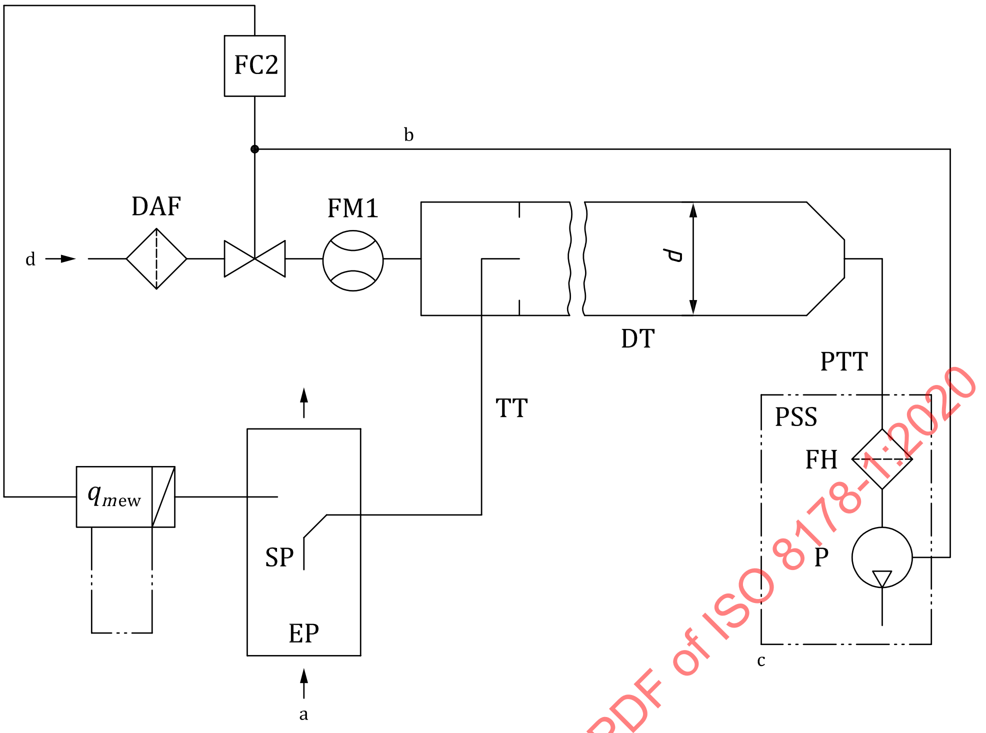
8.3.2 Partial flow dilution system

A dilution system is described based upon the dilution of a part of the exhaust stream. Splitting of the exhaust stream and the following dilution process may be done by different dilution system types. For subsequent collection of the particulates, the entire diluted exhaust gas or only a portion of the diluted exhaust gas is passed to the particulate sampling system (Figure 10). The first method is referred to as total-sampling type, the second method as fractional-sampling type. The calculation of the dilution ratio depends upon the type of system used. The following three types of systems should be used:

- isokinetic systems;
- flow control systems with concentration measurement;
- flow control systems with flow measurement.

A flow controlled system with flow measurement is described in Figure 8. Examples of other systems are described in Annex E.

With this system, a sample is taken from the bulk exhaust stream by setting the dilution air flow and the total diluted exhaust flow. The dilution ratio is determined from the difference of the two flow rates. Accurate calibration of the flow meters relative to one another is required, since the relative magnitude of the two flow rates can lead to significant errors at higher dilution ratios (of 15 and above). Flow control is very straightforward and is maintained by keeping the diluted exhaust flow rate constant and varying the dilution air flow rate, if needed.



[a] Exhaust.

[b] Optional to P (PSS).

[c] Particulate sampling system, see Figure 10.

[d] Dilution air.

Figure 8 — Partial-flow dilution system

Raw exhaust gas is transferred from the exhaust pipe EP to the dilution tunnel DT through the sampling probe SP and the transfer tube TT. The total flow through the tunnel is adjusted with the flow controller FC3 and the sampling pump P of the particulate sampling system (Figure 10). The dilution air flow is controlled by the flow controller FC2, which may use q_{mew} or q_{maw} and q_{mf} as command signals, for the desired exhaust split. The sample flow into DT is the difference between the total flow and the dilution air flow. The dilution air flow rate is measured with the flow measurement device FM1 and the total flow rate with the flow measurement device FM3 of the particulate sampling system (see Figure 10). The dilution ratio is calculated from these two flow rates.

Components of Figure 8

EP — exhaust pipe

The exhaust pipe may be insulated. To reduce the thermal inertia of the exhaust pipe, the thickness-to-diameter ratio should be 0,015 or less. The use of flexible sections shall be limited to a length-to-diameter ratio of 12 or less. Bends shall be minimized to reduce inertial deposition. If the system includes a test bed silencer, the silencer may also be insulated.

SP — sampling probe

Sizing the inside diameter of PM probes to approximate isokinetic sampling at the expected mean flow rate is recommended. The probe shall be an open tube facing upstream and preferably on the exhaust pipe centreline and may have a hat-shaped pre-classifier according to 8.1.1 and 8.1.3.

TT — transfer tube

The transfer tube shall meet the criteria as specified in 5.2.1.2 and 8.1.2.

FC2 — flow controller

A flow controller may be used to control the flow of the pressure blower PB and/or the suction blower SB. It may be connected to the exhaust, intake air or fuel flow signals and/or to the CO_2 or NO_x differential signals.

When using a pressurized air supply, FC2 directly controls the air flow.

FM1 — flow measurement device

Gas meter or other flow instrumentation to measure the dilution air flow. FM1 is optional if the pressure blower PB is calibrated to measure the flow.

DAF — dilution air filter

The dilution air (ambient air, purified air, or nitrogen) shall be filtered with a high-efficiency PM air (HEPA) filter.

DT — dilution tunnel

The dilution tunnel

— shall be of a sufficient length to cause complete mixing of the exhaust and dilution air under turbulent flow conditions;

— shall be constructed of stainless steel;

— may be heated to no greater than 52 °C wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 52 °C prior to the introduction of the exhaust in the dilution tunnel;

— may be insulated.

The engine exhaust shall be thoroughly mixed with the dilution air. For fractional-sampling systems, the mixing quality shall be checked after introduction into service by means of a CO_2 profile of the tunnel with the engine running (at least four equally spaced measuring points). If necessary, a mixing orifice may be used.

8.3.3 Full-flow dilution system

For subsequent collection of the particulates, a sample of the dilute exhaust gas is passed to the particulate sampling system (see Figure 10 and Figure 11). If this is done directly, it is referred to as single dilution. If the sample is diluted once more in the secondary dilution tunnel, it is referred to as double dilution. This is useful if the filter face temperature requirement cannot be met with single dilution. Although partly a dilution system, the double-dilution system is described as a modification of a particulate sampling system in Figure 11, since it shares most of the parts with a typical particulate sampling system.

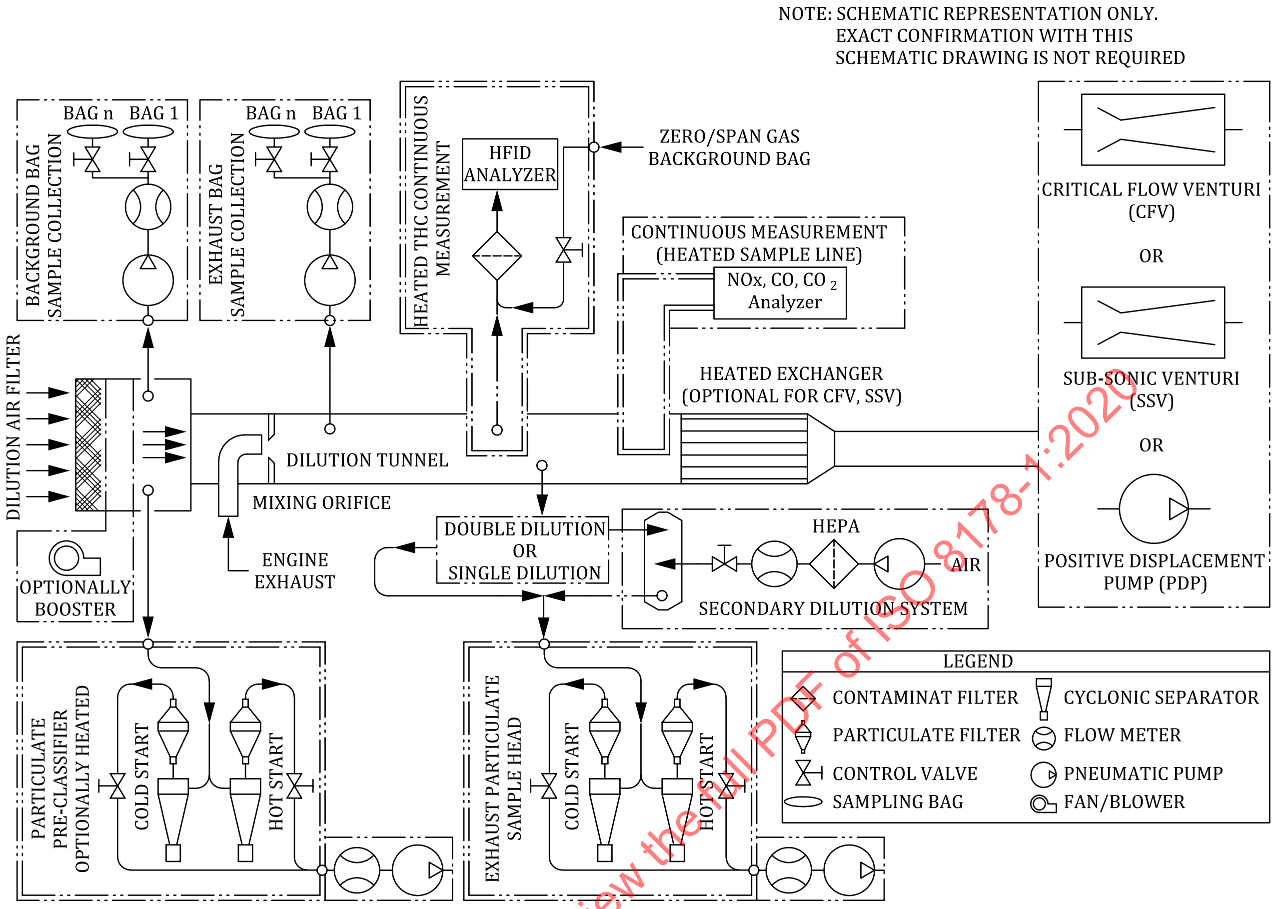


Figure 9 — Full-flow dilution system

The total amount of raw exhaust gas is mixed in the dilution tunnel (DT) with the dilution air. The diluted exhaust gas flow rate is measured either with a positive displacement pump (PDP) or with a critical-flow venturi (CFV). A heat exchanger (HE) or electronic flow compensation (EFC) may be used for proportional particulate sampling and for flow determination. Since particulate mass determination is based on the total diluted exhaust gas flow, it is not necessary to calculate the dilution ratio.

EP — exhaust pipe

The exhaust pipe length from the exit of the engine exhaust manifold, turbocharger outlet or after-treatment device to the dilution tunnel shall be not more than 10 m. If the system exceeds 4 m in length, then all tubing in excess of 4 m shall be insulated, except for an in-line smoke meter, if used. The radial thickness of the insulation shall be at least 25 mm. The thermal conductivity of the insulating material shall have a value no greater than 0,1 W/(m·K) measured at 673 K (400 °C). To reduce the thermal inertia of the exhaust pipe, the thickness-to-diameter ratio should be 0,015 or less. The use of flexible sections shall be limited to a length-to-diameter ratio of 12 or less.

PDP — positive displacement pump

The PDP meters total diluted exhaust flow from the number of pump revolutions and the pump displacement. The exhaust system backpressure shall not be artificially lowered by the PDP or dilution air inlet system. Static exhaust backpressure measured with the PDP system operating shall remain within ±1,5 kPa of the static pressure measured without connection to the PDP at identical engine speed and load. The gas mixture temperature immediately ahead of the PDP shall be within ±6 °C of the average operating temperature observed during the test, when no flow compensation is used. Flow compensation can only be used if the temperature at the inlet to the PDP does not exceed 50 °C.

CFV — critical flow venturi

CFV measures total diluted exhaust flow by maintaining the flow at choked conditions (critical flow). Static exhaust backpressure measured with the CFV system operating shall remain within ±1,5 kPa of the static pressure measured without connection to the CFV at identical engine speed and load. The gas mixture temperature immediately ahead of the CFV shall be within ±11 °C of the average operating temperature observed during the test, when no flow compensation is used.

SSV — subsonic venturi

SSV measures total diluted exhaust flow by using the gas flow of a subsonic venturi as a function of inlet pressure and temperature and pressure drop between venturi inlet and throat. Static exhaust backpressure measured with the SSV system operating shall remain within ±1,5 kPa of the static pressure measured without connection to the SSV at identical engine speed and load. The gas mixture temperature immediately ahead of the SSV shall be within ±11 °C of the average operating temperature observed during the test, when no flow compensation is used.

HE — heat exchanger (optional, if EFC is used)

The heat exchanger shall be of sufficient capacity to maintain the temperature within the limits required above.

EFC — electronic flow compensation (optional, if HE is used)

If the temperature at the inlet to either the PDP or CFV is not kept within the limits stated above, a flow compensation system is required for continuous measurement of the flow rate and control of the proportional sampling in the particulate system. For that purpose, the continuously measured flow rate signals are used accordingly to correct the sample flow rate through the particulate filters of the particulate sampling system (see Figure 10 and Figure 11).

DT — dilution tunnel

The dilution tunnel

- shall be small enough in diameter to cause turbulent flow (Reynolds Number greater than 4 000) and of sufficient length to cause complete mixing of the exhaust and dilution air – a mixing orifice may be used;
- shall be at least 75 mm in diameter;
- may be insulated.

The engine exhaust shall be directed downstream at the point where it is introduced into the dilution tunnel, and thoroughly mixed.

When using single dilution, a sample from the dilution tunnel is transferred to the particulate sampling system (Figure 10). The flow capacity of the PDP or CFV shall be sufficient to maintain the diluted exhaust at a temperature between 42 °C and 52 °C immediately before the particulate filter.

When using double dilution, a sample from the dilution tunnel is transferred to the secondary dilution tunnel where it is further diluted, and then passed through the sampling filters (Figure 11). The flow capacity of the PDP or CFV shall be sufficient to maintain the diluted exhaust stream in the DT at a temperature of less than or equal to 191 °C at the sampling zone. The secondary dilution system shall provide sufficient secondary dilution air to maintain the doubly diluted exhaust stream at a temperature between 42 °C and 52 °C immediately before the particulate filter.

DAF — dilution air filter

The dilution air (ambient air, purified air, or nitrogen) shall be filtered with a high-efficiency PM air (HEPA) filter.

PSP — particulate sampling probe

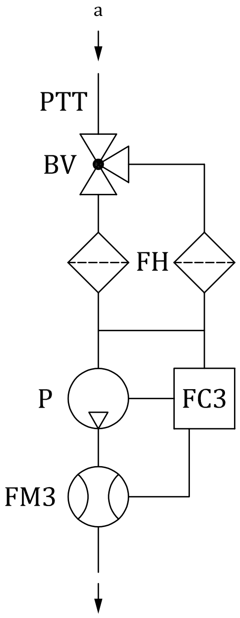
The probe is the leading section of PTT and

- shall be installed facing upstream at a point where the dilution air and exhaust gases are well mixed, i.e. on the dilution tunnel DT centreline of the dilution systems (see 8.3.2, 8.3.3 and Annex E), approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel;
- should have an inside diameter to approximate isokinetic sampling at the expected mean flow rate;
- may be heated to no greater than 52 °C wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 52 °C prior to the introduction of the exhaust in the dilution tunnel;
- may be insulated.

8.3.4 Particulate sampling system

The particulate sampling system is required for collecting the particulates on the particulate filter. In the case of total sampling partial-flow dilution, which consists of passing the entire diluted exhaust sample through the filters, the dilution (see Figure E.4) and sampling systems usually form an integral unit. In the case of fractional sampling partial-flow dilution or full-flow dilution, which consists of passing through the filters only a portion of the diluted exhaust, the dilution (Figures 8, 9, Figures E.1 to E.3 and E.5 to E.8) and sampling systems usually form different units. In this document, the double-dilution system (Figure 11) of a full-flow dilution system is considered to be a specific modification of a typical particulate sampling system as shown in Figure 10. The double-dilution system includes all important parts of the particulate sampling system, like filter holders and sampling pump, and additionally some dilution features, like a dilution air supply and a secondary dilution tunnel.

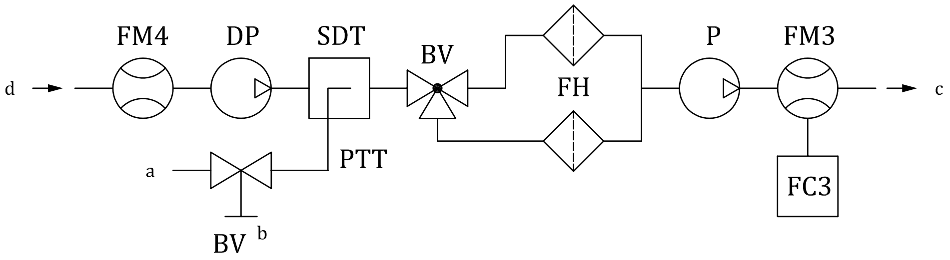
In order to avoid any impact on the control loops, the sample pump should be running throughout the complete test procedure. For the single-filter method, a bypass system shall be used for passing the sample through the sampling filters at the desired times. Interference of the switching procedure on the control loops shall be minimized.



[a] From dilution tunnel DT (see Figures 9 and E.1 to E.8).

Figure 10 — Particulate sampling system

A sample of the diluted exhaust gas is taken from the dilution tunnel DT of a partial-flow or full-flow dilution system through the particulate sampling probe PSP and the particulate transfer tube PTT by means of the sampling pump P. The sample is passed through the filter holder(s) FH that contain the particulate sampling filters. The sample flow rate is controlled by the flow controller FC3. If electronic flow compensation EFC (see Figure 9) is used, the diluted exhaust gas flow is used as command signal for FC3.



[a] From dilution tunnel DT (see Figure 9).

[b] Optional.

[c] Vent.

[d] Dilution air

Figure 11 — Secondary dilution and particulate sampling system (full-flow system only)

A sample of the diluted exhaust gas is transferred from the dilution tunnel DT of a full-flow dilution system through the particulate sampling probe PSP and the particulate transfer tube PTT to the secondary dilution tunnel SDT, where it is diluted once more. The sample is then passed through the filter holder(s) FH that contain the particulate sampling filters. The dilution air flow rate is usually constant whereas the sample flow rate is controlled by the flow controller FC3. If electronic flow compensation EFC (see Figure 9) is used, the total diluted exhaust gas flow is used as command signal for FC3.

Components of Figure 10 and Figure 11

PSP — particulate sampling probe

The particulate sampling probe, not shown in the figures, is the leading section of the particulate transfer tube PTT.

The probe

- shall be installed facing upstream at a point where the dilution air and exhaust gas are well mixed (see 8.3.2 and 8.3.3), approximately 10 tunnel diameters downstream of the point where the exhaust enters the dilution tunnel;
- should have an inside diameter to approximate isokinetic sampling at the expected mean flow rate;
- may be heated to no greater than 52 °C wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 52 °C prior to the introduction of the exhaust into the dilution tunnel;
- may be insulated.

PTT — particulate transfer tube

The transfer tube shall meet the criteria as specified in 5.2.1.2 and 8.1.2.

SDT — secondary dilution tunnel (Figure 11 only)

The secondary dilution tunnel should have a minimum diameter of 75 mm, and should be of sufficient length so as to provide a residence time of at least 0,25 s for the doubly diluted sample. The primary filter holder FH shall be located within 300 mm of the exit of the SDT.

The secondary dilution tunnel

- may be heated to no greater than 52 °C wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 52 °C prior to the introduction of the exhaust into the dilution tunnel;
- may be insulated.

FH — filter holder

The filter holder

- shall have a 12,5° (from centre) divergent cone angle to a stainless-steel transition from the transfer-line inside diameter to the exposed diameter of the filter face to minimize turbulent deposition and to deposit PM evenly on a filter
- may be heated to no greater than 52 °C wall temperature by direct heating or by dilution air pre-heating, provided the air temperature does not exceed 52 °C prior to the introduction of the exhaust into the dilution tunnel;
- may be insulated;

P — sampling pump

The particulate sampling pump shall be located sufficiently distant from the tunnel so that the inlet gas temperature is maintained constant (±3 °C), if flow correction by FC3 is not used.

DP — dilution air pump (Figure 11 only)

The dilution air pump shall be located so that the secondary dilution air is supplied at a temperature of 25 °C ± 5 °C.

FC3 — flow controller

A flow controller shall be used to compensate the particulate sample flow rate for temperature and backpressure variations in the sample path, if no other means are available. The flow controller is required if electronic flow compensation EFC (see Figure 9) is used.

FM3 — flow measurement device

The gas meter or flow instrumentation for the particulate sample flow shall be located sufficiently distant from the sampling pump P so that the inlet gas temperature remains constant (±3 °C), if flow correction by FC3 is not used.

FM4 — flow measurement device (Figure 11 only)

The gas meter or flow instrumentation for the dilution air flow shall be located so that the inlet gas temperature is maintained constant (±3 °C).

BV — ball valve (optional)

The ball valve shall have an inside diameter not less than the inside diameter of the particulate transfer tube PTT, and a switching time of less than 0,5 s.

If the ambient temperature in the vicinity of PSP, PTT, SDT and FH is below 20 °C, precautions should be taken to avoid particle losses on to the cool wall of these parts. Therefore, heating and/or insulating these parts within the limits given in the respective descriptions is recommended.

At high engine loads, the above parts may be cooled by a non-aggressive means such as a circulating fan, as long as the temperature of the cooling medium is not below 15 °C.

8.4 Particle number measurement equipment

8.4.1 System overview

The particle sampling system shall consist of a probe or sampling point extracting a sample from a homogenously mixed flow in a dilution system as described in 8.3.2 and 8.3.3, a volatile particle remover (VPR) upstream of a particle number counter (PNC) and suitable transfer tubing.

It is recommended that a particle size pre-classifier (e.g. cyclone, impactor, etc.) be located prior to the inlet of the VPR. However, a sample probe acting as an appropriate size-classification device, such as that shown in Figure 7, is an acceptable alternative to the use of a particle size pre-classifier. In the case of partial flow dilution systems it is acceptable to use the same pre-classifier for particulate mass and particle number sampling, extracting the particle number sample from the dilution system downstream of the pre-classifier. Alternatively, separate pre-classifiers may be used, extracting the particle number sample from the dilution system upstream of the particulate mass pre-classifier.

8.4.2 General requirements

The particle sampling point shall be located within a dilution system or may optionally be located in the raw gas stream.

The sampling probe tip or particle sampling point and particle transfer tube (PTT) together comprise the particle transfer system (PTS). The PTS conducts the sample from the dilution tunnel or from the undiluted exhaust stream to the entrance of the particle number measurement device.

The VPR shall include devices for sample dilution and for volatile particle removal.

All parts of the dilution system and the sampling system from the exhaust pipe up to the PNC, which are in contact with raw and diluted exhaust gas, shall be designed to minimize deposition of the particles. All parts shall be made of electrically conductive materials that do not react with exhaust gas components, and shall be electrically grounded to prevent electrostatic effects.

The particle sampling system shall incorporate good aerosol sampling practice that includes the avoidance of sharp bends and abrupt changes in cross-paragraph, the use of smooth internal surfaces and the minimisation of the length of the sampling line. Gradual changes in the cross-section are permissible.

8.4.3 Specific requirements

The particle sample shall not pass through a pump before passing through the PNC.

A sample pre-classifier is recommended.

8.4.3.1 Requirements for the sample preconditioning unit

The sample preconditioning unit shall:

- be capable of diluting the sample in one or more stages to achieve a particle number concentration below the upper threshold of the single particle count mode of the PNC and a gas temperature below 35 °C at the inlet to the PNC;
- include an initial heated dilution stage which outputs a sample at a temperature of ≥150 °C and ≤400 °C, and dilutes by a factor of at least 10;
- control heated stages to constant nominal operating temperatures, within the range specified in this subclause, to a tolerance of ±10 °C; provide an indication of whether or not heated stages are at their correct operating temperatures;

- achieve a particle concentration reduction factor ($f_r(d_i)$), as defined in 9.7.2 below, for particles of 30 nm and 50 nm electrical mobility diameters, that is no more than 30 % and 20 % respectively higher, and no more than 5 % lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole;
- also achieve >99,0 % vaporisation of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet concentration of ≥10 000 cm^{-3}, by means of heating and reduction of partial pressures of the tetracontane.

8.4.3.2 Requirements for the PNC

The PNC shall:

- operate under full flow operating conditions;
- have a counting accuracy of ±10 % across the range 1 cm^{-3} to the upper threshold of the single particle count mode of the PNC against a traceable standard. At concentrations below 100 cm^{-3} measurements averaged over extended sampling periods may be required to demonstrate the accuracy of the PNC with a high degree of statistical confidence;
- have a readability of at least 0,1 particle cm^{-3} at concentrations below 100 cm^{-3};
- have a linear response to particle concentrations over the full measurement range in single particle count mode;
- have a data reporting frequency equal to or greater than 0,5 Hz;
- have a t_{90} response time over the measured concentration range of less than 5 s;
- incorporate a coincidence correction function up to a maximum 10 % correction, and may make use of an internal calibration factor as determined in 9.7.1, but shall not make use of any other algorithm to correct for or define the counting efficiency;
- have counting efficiencies at particle sizes of 23 nm (±1 nm) and 41 nm (±1 nm) electrical mobility diameter of 50 % (±12 %) and >90 % respectively. These counting efficiencies may be achieved by internal (for example; control of instrument design) or external (for example; size pre-classification) means;

If the PNC makes use of a working liquid, it shall be replaced at the frequency specified by the instrument manufacturer.

Where they are not held at a known constant level at the point at which PNC flow rate is controlled, the pressure and/or temperature at inlet to the PNC shall be measured and reported for the purposes of correcting particle concentration measurements to standard conditions.

The sum of the residence time of the PTS, VPR and OT plus the t_{90} response time of the PNC shall be no greater than 20 s.

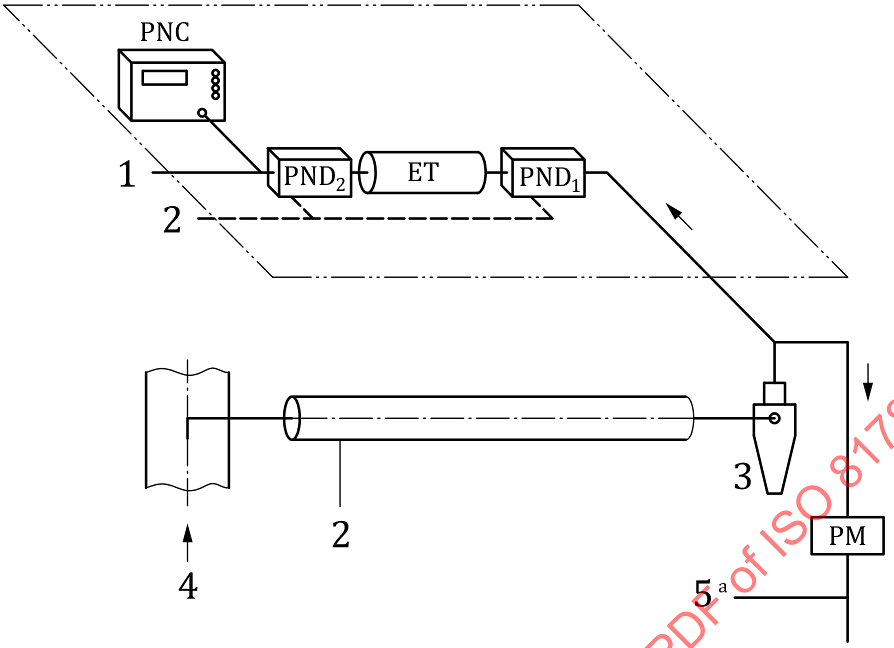
The transformation time of the entire particle number sampling system (PTS, VPR, OT and PNC) shall be determined by aerosol switching directly at the inlet of the PTS. The aerosol switching shall be done in less than 0,1 s. The aerosol used for the test shall cause a concentration change of at least 60 % full scale (FS).

The concentration trace shall be recorded. For time alignment of the particle number concentration and exhaust flow signals, the transformation time is defined as the time from the change (t_0) until the response is 50 % of the final reading (t_{50}).

8.4.4 Typical system description

The following subclause contains the typical practice for measurement of particle number. However, any system meeting the performance specifications in 8.4.2 and 8.4.3 is acceptable.

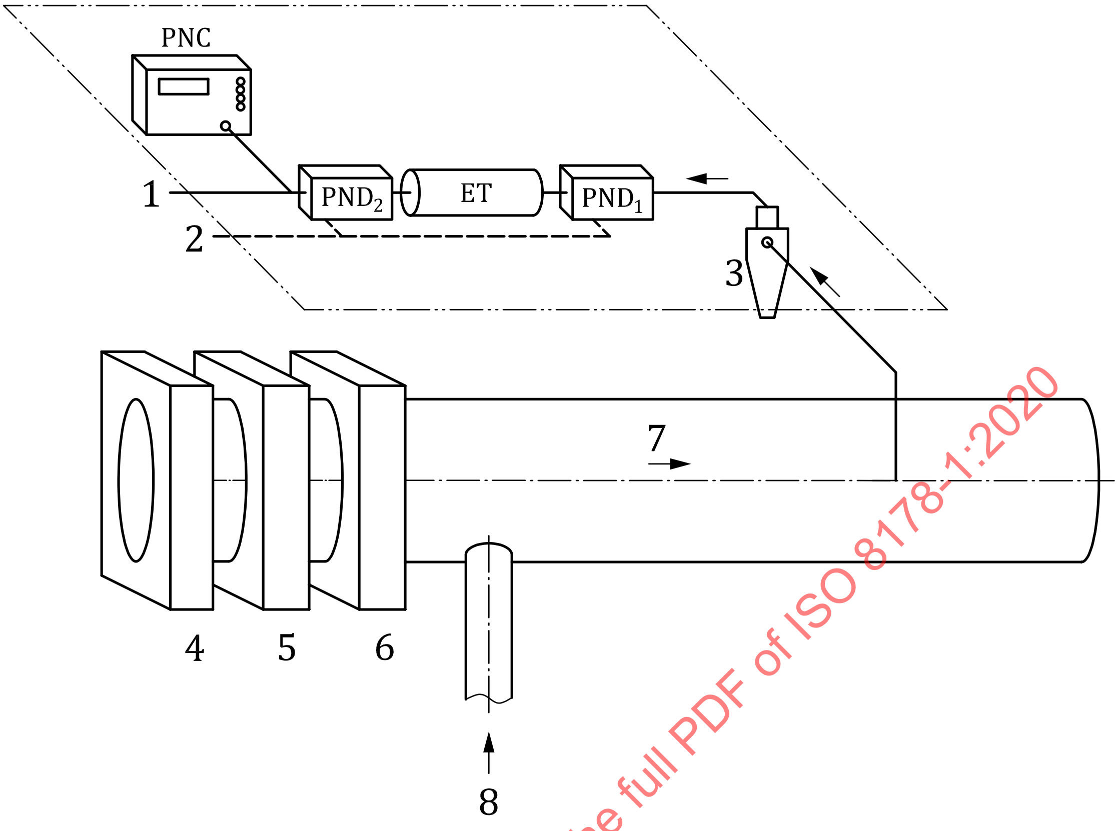
Figures 12 to 14 are schematic drawings of the typical particle sampling system configures for partial flow dilution, full flow dilution and raw sampling systems respectively.



Key

1	excess air	4	from engine exhaust
2	filtered air	5	make-up air
3	cyclone	a	Alternatively, the control software might account for the flow removed by the PN system.

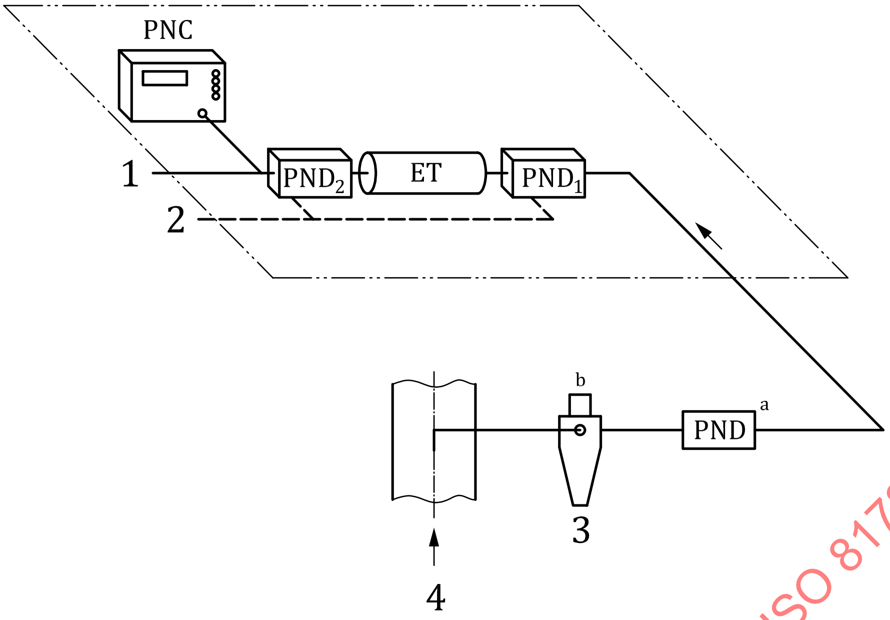
Figure 12 — Schematic of typical particle sampling system — Partial flow sampling



Key

1	excess air	5	LEPA
2	filtered air	6	HEPA
3	cyclone	7	flow direction
4	act. carbon	8	from engine exhaust

Figure 13 — Schematic of typical particle sampling system — Full flow sampling



Key

1	excess air
2	filtered air
3	pre-classifier or sample probe according to Figure 7
4	from engine exhaust
a	Optional.
b	In case a pre-classifier is used, it can be installed everywhere upstream of PND$_1$.

Figure 14 — Schematic of typical particle sampling system — Raw sampling

8.4.4.1 Sampling system description

The particle sampling system shall consist of a sampling probe tip or particle sampling point in the raw exhaust or dilution system, a particle transfer tube (PTT), a particle pre-classifier (PCF) and a volatile particle remover (VPR) upstream of the particle number concentration measurement (PNC) unit. The VPR shall include devices for sample dilution (particle number diluters: PND 1 and PND 2) and particle evaporation (Evaporation tube, ET).

The sampling probe or sampling point for the test gas flow shall be so arranged within the raw exhaust or dilution tract that a representative sample gas flow is taken from a homogeneous diluent/exhaust mixture. The sum of the residence time of the system plus the t_{90} response time of the PNC shall be no greater than 20 s.

8.4.4.2 Particle transfer system

8.4.4.2.1 Diluted particle sampling

In the case of full flow dilution systems and partial flow dilution systems of the fractional sampling type (as described in 8.3.2 and 8.3.3) the sampling probe shall be installed near the tunnel centre line, 10 to 20 tunnel diameters downstream of the gas inlet, facing upstream into the tunnel gas flow with its axis at the tip parallel to that of the dilution tunnel. The sampling probe shall be positioned within the dilution tract so that the sample is taken from a homogeneous diluent/exhaust mixture.

In the case of partial flow dilution systems of the total sampling type (as described in 8.3.2) the particle sampling point or sampling probe shall be located in the particulate transfer tube, upstream of the particulate filter holder, flow measurement device and any sample/bypass bifurcation point. The sampling point or sampling probe shall be positioned so that the sample is taken from a homogeneous diluent/exhaust mixture. The dimensions of the particle sampling probe should be sized not to interfere with the operation of the partial flow dilution system.

Sample gas drawn through the PTS shall meet the following conditions:

- In the case of full flow dilution systems, it shall have a flow Reynolds number (*Re*) of <1 700.
- In the case of partial flow dilution systems, it shall have a flow Reynolds number (*Re*) of <1 700 in the PTT i.e. downstream of the sampling probe or point.
- It shall have a residence time in the PTS of ≤3 s.

Any other sampling configuration for the PTS for which equivalent particle penetration at 30 nm can be demonstrated will be considered acceptable.

The outlet tube (OT) conducting the diluted sample from the VPR to the inlet of the PNC shall have the following properties:

- It shall have an internal diameter of ≥4 mm.
- Sample Gas flow through the OT shall have a residence time of ≤0,8 s.

Any other sampling configuration for the OT for which equivalent particle penetration at 30 nm can be demonstrated will be considered acceptable.

8.4.4.2.2 Raw particle sampling

The dimension of the particle sampling probe shall be sized not to interfere with the operation of other exhaust gas measurement instruments.

The particle number counting system may include a primary dilution stage in order to maintain the temperature within the limits specified by the manufacturer of the device.

Particle number concentration is not a conserved quantity like particulate mass. Therefore, PN measurements strongly depend on sample location and sampling method due to e.g. coagulation and diffusion effects. As an alternative to diluted particle sampling, raw particle sampling can be applied, if agreed by the parties involved.

It should be noted that PN results determined with raw particle sampling will not necessarily be comparable to PN results determined with diluted particle sampling.

8.4.4.3 Particle pre-classifier

A particle pre-classifier is recommended and if used, it shall be located upstream of the VPR. The pre-classifier 50 % cut point particle diameter shall be between 2,5 µm and 10 µm at the volumetric flow rate selected for sampling particle number emissions. The pre-classifier shall allow at least 99 % of the mass concentration of 1 µm particles entering the pre-classifier to pass through the exit of the pre-classifier at the volumetric flow rate selected for sampling particle number emissions. In the case of partial flow dilution systems, it is acceptable to use the same pre-classifier for particulate mass and particle number sampling, extracting the particle number sample from the dilution system downstream of the pre-classifier. Alternatively, separate pre-classifiers may be used, extracting the particle number sample from the dilution system upstream of the particulate mass pre-classifier.

8.4.4.4 Volatile particle remover (VPR)

The VPR shall comprise one particle number diluter (PND 1), an evaporation tube and a second diluter (PND 2) in series. This dilution function is to reduce the number concentration of the sample entering the particle concentration measurement unit to less than the upper threshold of the single particle count mode of the PNC and to suppress nucleation within the sample. The VPR shall provide an indication of whether or not PND 1 and the evaporation tube are at their correct operating temperatures.

The VPR shall achieve >99,0 % vaporisation of 30 nm tetracontane ($CH_3(CH_2)_{38}CH_3$) particles, with an inlet concentration of ≥10 000 cm^{-3}, by means of heating and reduction of partial pressures of the tetracontane. It shall also achieve a particle concentration reduction factor (f_r) for particles of 30 nm and 50 nm electrical mobility diameters, that is no more than 30 % and 20 % respectively higher, and no more than 5 % lower than that for particles of 100 nm electrical mobility diameter for the VPR as a whole.

8.4.4.5 First particle number dilution device (PND 1)

The first particle number dilution device shall be specifically designed to dilute particle number concentration and operate at a (wall) temperature of 150 °C to 400 °C. The wall temperature set point should be held at a constant nominal operating temperature, within this range, to a tolerance of ±10 °C and not exceed the wall temperature of the ET (8.4.4.6). The diluter should be supplied with HEPA filtered dilution air and be capable of a dilution factor of 10 to 200 times.

8.4.4.6 Evaporation tube (ET)

The entire length of the ET shall be controlled to a wall temperature greater than or equal to that of the first particle number dilution device and the wall temperature held at a fixed nominal operating temperature between 300 °C and 400 °C, to a tolerance of ±10 °C.

8.4.4.7 Second particle number dilution device (PND 2)

PND 2 shall be specifically designed to dilute particle number concentration. The diluter shall be supplied with HEPA filtered dilution air and be capable of maintaining a single dilution factor within a range of 10 to 30 times. The dilution factor of PND 2 shall be selected in the range between 10 and 15 such that particle number concentration downstream of the second diluter is less than the upper threshold of the single particle count mode of the PNC and the gas temperature prior to entry to the PNC is <35 °C.

8.4.4.8 Particle number counter (PNC)

The PNC shall meet the requirements of 8.4.3.2.

9 Calibration and verification

9.1 Calibration and performance checks

9.1.1 General

This subclause describes required calibrations and verifications of measurement systems. See 5.3, Clause 6 and 7.3 for specifications that apply to individual instruments.

Calibrations or verifications shall be generally performed over the complete measurement chain.

If a calibration or verification for a portion of a measurement system is not specified, that portion of the system shall be calibrated and its performance verified at a frequency consistent with any recommendations from the measurement system manufacturer and consistent with good engineering judgment.

Internationally recognized-traceable standards shall be used to meet the tolerances specified for calibrations and verifications.

9.1.2 Summary of calibration and verification

Table 6 summarizes the calibrations and verifications described in Clause 9 and indicates when these have to be performed.

Table 6 — Summary of required calibration and verifications

Type of calibration or verification	Minimum frequency[a]
9.1.3: Accuracy, repeatability and noise	Accuracy: Not required, but advised for initial installation. Repeatability: Not required, but advised for initial installation. Noise: Not required, but advised for initial installation.
9.1.4: Linearity verification	Speed: Upon initial installation, within 370 days before testing and after major maintenance. Torque: Upon initial installation, within 370 days before testing and after major maintenance. Intake-air, dilution air, diluted exhaust flows and batch sampler flow rates: Upon initial installation, within 370 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. Raw exhaust flow: Upon initial installation, within 185 days before testing and after major maintenance, unless flow is verified by propane check or by carbon or oxygen balance. Gas dividers: Upon initial installation, within 370 days before testing, and after major maintenance. Gas analysers (unless otherwise noted): Upon initial installation, within 35 days before testing and after major maintenance. FTIR analyser: Upon initial installation, within 370 days before testing and after major maintenance. PM balance: Upon initial installation, within 370 days before testing and after major maintenance. Stand-alone pressure, temperature, and dew point: Upon initial installation, within 370 days before testing and after major maintenance.
9.1.5: Continuous gas analyser system response and updating-recording verification – for gas analysers not continuously compensated for other gas species	Upon initial installation or after system modification that would affect response.
9.1.6: Continuous gas analyser system response and updating-recording verification – for gas analysers continuously compensated for other gas species	Upon initial installation or after system modification that would affect response.
9.9.1: Torque	Upon initial installation and after major maintenance.
9.10: Pressure, temperature, dew point	Upon initial installation and after major maintenance.
9.11.1: Fuel flow	Upon initial installation and after major maintenance.
9.11.2: Intake flow	Upon initial installation and after major maintenance.
9.11.3: Exhaust flow	Upon initial installation and after major maintenance.
9.8: Diluted exhaust flow (CVS and PFD)	Upon initial installation and after major maintenance.
9.8.5: CVS/PFD and batch sampler verification[b]	Upon initial installation, within 35 days before testing, and after major maintenance. (Propane check)
9.8.5.8: Sample Dryer verification	For thermal chillers: upon installation and after major maintenance. For osmotic membranes; upon installation, within 35 days of testing and after major maintenance

[a] Perform calibrations and verifications more frequently, according to measurement system manufacturer instructions and good engineering judgment.

[b] The CVS verification is not required for systems that agree within ±2 % based on a chemical balance of carbon or oxygen of the intake air, fuel, and diluted exhaust.

NOTE Calibration and verification frequency of the particle number counting system is not referenced in this table but defined in 9.7.

Table 6 *(continued)*

Type of calibration or verification	Minimum frequency[a]
9.3: Vacuum leak	Upon installation of the sampling system. Before each laboratory test according to 5.1: within 8 hours before the start of the first test interval of each duty cycle sequence, after maintenance such as pre-filter changes.
9.5.8.1: CO_2 NDIR H_2O interference	Upon initial installation and after major maintenance.
9.5.8.2: CO NDIR CO_2 and H_2O interference	Upon initial installation and after major maintenance.
9.5: FID calibration THC FID optimization and THC FID verification	Calibrate all FID analysers: upon initial installation, and after major maintenance. Optimize, and determine CH_4 response for the THC FID analysers. Verify CH_4 response for the THC FID analysers: upon initial installation, within 185 days before testing, and after major maintenance.
9.5.6: Raw exhaust FID O_2 interference	For all FID analysers: upon initial installation, and after major maintenance. For THC FID analysers: upon initial installation, after major maintenance, and after FID optimization according to 9.5.
9.5.7: Non-methane cutter penetration	Upon initial installation, within 185 days before testing, and after major maintenance.
9.5.9.1: CLD CO_2 and H_2O quench	Upon initial installation and after major maintenance.
9.5.9.2: NDUV HC and H_2O interference	Upon initial installation and after major maintenance.
9.5.9.3: Cooling bath NO_2 penetration (chiller)	Upon initial installation and after major maintenance.
9.5.9.4: Interference verification for SO_2 NDIR or FTIR analysers	Upon initial installation and after major maintenance.
9.5.9.5: Cross-interference check compensation for NH_3 channels using IR and UV	Upon initial installation and after major maintenance.
9.5.9.6: N_2O analyser interference	Upon initial installation and after major maintenance.
9.5.9.7: Interference verification for NO_x laser infrared analysers	Upon initial installation and after major maintenance.
9.4: NO_2-to-NO converter conversion	Upon initial installation, within 35 days before testing, and after major maintenance.
9.6.3: PM balance and weighing	Independent verification: upon initial installation, within 370 days before testing, and after major maintenance. Zero, span, and reference sample verifications: within 12 hours of weighing, and after major maintenance.

[a] Perform calibrations and verifications more frequently, according to measurement system manufacturer instructions and good engineering judgment.

[b] The CVS verification is not required for systems that agree within ±2 % based on a chemical balance of carbon or oxygen of the intake air, fuel, and diluted exhaust.

NOTE Calibration and verification frequency of the particle number counting system is not referenced in this table but defined in 9.7.

9.1.3 Verifications for accuracy, repeatability, and noise

The performance values for individual instruments specified in Table 5 are the basis for the determination of the accuracy, repeatability, and noise of an instrument.

It is not required to verify instrument accuracy, repeatability, or noise. However, it may be useful to consider these verifications to define a specification for a new instrument, to verify the performance of a new instrument upon delivery, or to troubleshoot an existing instrument.

9.1.4 Linearity check

9.1.4.1 Scope and frequency

A linearity verification shall be performed on each measurement system listed in Table 7 at least as frequently as indicated in the table, consistent with measurement system manufacturer recommendations and good engineering judgment. The intent of a linearity verification is to determine that a measurement system responds proportionally over the measurement range of interest. A linearity verification shall consist of introducing a series of at least 10 reference values to a measurement system, unless otherwise specified. The measurement system quantifies each reference value. The measured values shall be collectively compared to the reference values by using a least squares linear regression and the linearity criteria specified in Table 7 of this paragraph.

9.1.4.2 Performance requirements

If a measurement system does not meet the applicable linearity criteria in Table 7, the deficiency shall be corrected by re-calibrating, servicing, or replacing components as needed. The linearity verification shall be repeated after correcting the deficiency to ensure that the measurement system meets the linearity criteria.

9.1.4.3 Procedure

The following linearity verification protocol shall be used:

a) A measurement system shall be operated at its specified temperatures, pressures, and flows.

b) The instrument shall be zeroed as it would before an emission test by introducing a zero signal. For gas analysers, a zero gas shall be used that meets the specifications of 9.2 and it shall be introduced directly at the analyser port.

c) The instrument shall be spanned as it would before an emission test by introducing a span signal. For gas analysers, a span gas shall be used that meets the specifications of 9.2 and it shall be introduced directly at the analyser port.

d) After spanning the instrument, zero shall be checked with the same signal which has been used in b) of this subclause. Based on the zero reading, good engineering judgment shall be used to determine whether or not to re-zero and or re-span the instrument before proceeding to the next step.

e) For all measured quantities manufacturer recommendations and good engineering judgment shall be used to select the reference values, $y_{\text{ref}i}$, that cover the full range of values that are expected during emission testing, thus avoiding the need of extrapolation beyond these values. A zero reference signal shall be selected as one of the reference values of the linearity verification. For stand-alone pressure and temperature linearity verifications, at least three reference values shall be selected. For all other linearity verifications, at least ten reference values shall be selected.

f) Instrument manufacturer recommendations and good engineering judgment shall be used to select the order in which the series of reference values will be introduced.

g) Reference quantities shall be generated and introduced as described in 9.1.4.4. For gas analysers, gas concentrations known to be within the specifications of 9.2 shall be used and they shall be introduced directly at the analyser port.

h) Time for the instrument to stabilize while it measures the reference value shall be allowed.

i) At a recording frequency of at least the minimum recording frequency, the reference value shall be measured for 30 s and the arithmetic mean of the recorded values, $\bar{y}_i$ be recorded.

j) Steps in g) through i) of this subclause shall be repeated until all reference quantities are measured.

k) The arithmetic means $\bar{y}_i$, and reference values, $y_{\text{ref}i}$, shall be used to calculate least-squares linear regression parameters and statistical values to compare to the minimum performance criteria specified in Table 7. The calculations described in Annex D shall be used.

9.1.4.4 Reference signals

This subclause describes methods for generating reference values for the linearity-verification protocol in 9.1.4.3. Reference values shall be used that simulate actual values, or an actual value shall be introduced and measured with a reference-measurement system. In the latter case, the reference value is the value reported by the reference-measurement system. Reference values and reference-measurement systems shall be internationally traceable.

For temperature measurement systems with sensors like thermocouples, RTDs, and thermistors, the linearity verification may be performed by removing the sensor from the system and using a simulator in its place. A simulator that is independently calibrated and cold junction compensated, as necessary shall be used. The internationally traceable simulator uncertainty scaled to temperature shall be less than 0,5 % of maximum operating temperature T_{max}. If this option is used, it is necessary to use sensors that the supplier states are accurate to better than 0,5 % of T_{max} compared to their standard calibration curve.

9.1.4.5 Measurement systems that require linearity verification

Table 7 indicates measurement systems that require linearity verifications. For this table the following provisions apply:

a) A linearity verification shall be performed more frequently if the instrument manufacturer recommends it or based on good engineering judgment.

b) "min" refers to the minimum reference value used during the linearity verification.

Note that this value may be zero or a negative value depending on the signal.

c) "max" generally refers to the maximum reference value used during the linearity verification. For example for gas dividers, x_{max} is the undivided, undiluted, span gas concentration. The following are special cases where "max" refers to a different value:

  1) for PM balance linearity verification, m_{max} refers to the typical mass of a PM filter;

  2) for torque linearity verification, T_{max} refers to the manufacturer's specified engine torque peak value of the highest torque engine to be tested;

d) The specified ranges are inclusive. For example, a specified range of 0,98-1,02 for the slope a_1 means $0{,}98 \leq a_1 \leq 1{,}02$.

e) These linearity verifications are not required for systems that pass the flow-rate verification for diluted exhaust as described in 9.8.5. for the propane check or for systems that agree within ±2 % based on a chemical balance of carbon or oxygen of the intake air, fuel, and exhaust.

f) a_1 criteria for these quantities shall be met only if the absolute value of the quantity is required, as opposed to a signal that is only linearly proportional to the actual value.

g) Stand-alone temperatures include engine temperatures and ambient conditions used to set or verify engine conditions; temperatures used to set or verify critical conditions in the test system; and temperatures used in emissions calculations:

  1) These temperature linearity checks are required: Air intake; aftertreatment bed(s) (for engines tested with aftertreatment devices on cycles with cold start criteria); dilution air for PM sampling CVS, double dilution, and partial flow systems); PM sample; and chiller sample (for gaseous sampling systems that use chillers to dry samples).

  2) These temperature linearity checks are only required if specified by the engine manufacturer: Fuel inlet; test cell charge air cooler air outlet (for engines tested with a test cell heat exchanger

simulating a vehicle/machine charge air cooler); test cell charge air cooler coolant inlet (for engines tested with a test cell heat exchanger simulating a vehicle/machine charge air cooler); and oil in the sump/pan; coolant before the thermostat (for liquid cooled engines).

h) Stand-alone pressures include engine pressures and ambient conditions used to set or verify engine conditions; pressures used to set or verify critical conditions in the test system; and pressures used in emissions calculations:

   1) Required pressure linearity checks are: air intake restriction; exhaust back pressure; barometer; CVS inlet gage pressure (if measurement using CVS); chiller sample (for gaseous sampling systems that use chillers to dry samples).

   2) Pressure linearity checks that are required only if specified by the engine manufacturer: test cell charge air cooler and interconnecting pipe pressure drop (for turbo-charged engines tested with a test cell heat exchanger simulating a vehicle/machine charge air cooler) fuel inlet; and fuel outlet.

Table 7 — Measurement systems that require linearity verifications

Measurement System	Quantity	Minimum verification frequency	Linearity Criteria			
			$\lvert x_{\mathrm{min}} \times (a_1 - 1) + a_0 \rvert$	a	S_{EE}	r^2
Engine speed	n	Within 370 days before testing	≤0,05 % n_{max}	0,98-1,02	≤2 % n_{max}	≥0,990
Engine torque	T	Within 370 days before testing	≤1 % T_{max}	0,98-1,02	≤2 % T_{max}	≥0,990
Fuel flow rate	q_{mf}	Within 370 days before testing	≤1 % $q_{m,\mathrm{max}}$	0,98-1,02	≤2 % $q_{m,\mathrm{max}}$	≥0,990
Intake-air flow rate[a]	q_V	Within 370 days before testing	≤1 % $q_{V,\mathrm{max}}$	0,98-1,02	≤2 % $q_{V,\mathrm{max}}$	≥0,990
Dilution air flow rate[a]	q_V	Within 370 days before testing	≤1 % $q_{V,\mathrm{max}}$	0,98-1,02	≤2 % $q_{V,\mathrm{max}}$	≥0,990
Diluted exhaust flow rate[a]	q_V	Within 370 days before testing	≤1 % $q_{V,\mathrm{max}}$	0,98-1,02	≤2 % $q_{V,\mathrm{max}}$	≥0,990
Raw exhaust flow rate[a]	q_V	Within 185 days before testing	≤1 % $q_{V,\mathrm{max}}$	0,98-1,02	≤2 % $q_{V,\mathrm{max}}$	≥0,990
Batch sampler flow rates[a]	q_V	Within 370 days before testing	≤1 % $q_{V,\mathrm{max}}$	0,98-1,02	≤2 % $q_{V,\mathrm{max}}$	≥0,990
Gas dividers	x/x_{span}	Within 370 days before testing	≤0,5 % x_{max}	0,98-1,02	≤2 % x_{max}	≥0,990
Gas analysers	x	Within 35 days before testing	≤0,5 % x_{max}	0,99-1,01	≤1 % x_{max}	≥0,998
PM balance	m	Within 370 days before testing	≤1 % m_{max}	0,99-1,01	≤1 % m_{max}	≥0,998

[a] For flow meters that determine standard volumetric flow rate, you may substitute it for molar flow rate as the quantity and substitute maximum standard flow rate for maximum molar flow rate.

Table 7 *(continued)*

Measurement System	Quantity	Minimum verification frequency	Linearity Criteria			
			$\lvert x_{\text{min}} \times (a_1 - 1) + a_0 \rvert$	a	S_{EE}	r^2
Stand-alone pressures	p	Within 370 days before testing	$\leq 1\ \%\ p_{\text{max}}$	0,99-1,01	$\leq 1\ \%\ p_{\text{max}}$	≥0,998
Dew point for intake air, PM-stabilization and balance environments.	T_{dew}	Upon initial installation, within 370 days before testing and after major maintenance.	$\leq 0{,}5\ \%\ T_{\text{dewmax}}$	0,99-1,01	$\leq 0{,}5\ \%\ T_{\text{dewmax}}$	≥0,998
Other dew point measurements	T_{dew}	Upon initial installation, within 370 days before testing and after major maintenance.	$\leq 1\ \%\ T_{\text{dewmax}}$	0,99-1,01	$\leq 1\ \%\ T_{\text{dewmax}}$	≥0,998
Analog-to-digital conversion of stand-alone temperature signals	T	Within 370 days before testing	$\leq 1\ \%\ T_{\text{max}}$	0,99-1,01	$\leq 1\ \%\ T_{\text{max}}$	≥0,998

[a] For flow meters that determine standard volumetric flow rate, you may substitute it for molar flow rate as the quantity and substitute maximum standard flow rate for maximum molar flow rate.

9.1.5 Continuous gas analyser system-response and updating-recording verification

This subclause describes a general verification procedure for continuous gas analyser system response and update recording. See 9.1.6 for verification procedures for compensation type analysers.

9.1.5.1 Scope and frequency

This verification shall be performed after installing or replacing a gas analyser that is used for continuous sampling. Also this verification shall be performed if the system is reconfigured in a way that would change system response. This verification is needed for continuous gas analysers used for transient or ramped-modal testing but is not needed for batch gas analyser systems or for continuous gas analyser systems used only for discrete-mode testing.

9.1.5.2 Measurement principles

This test verifies that the updating and recording frequencies match the overall system response to a rapid change in the value of concentrations at the sample probe. Gas analyser systems shall be optimized such that their overall response to a rapid change in concentration is updated and recorded at an appropriate frequency to prevent loss of information. This test also verifies that continuous gas analyser systems meet a minimum response time.

The system settings for the response time evaluation shall be exactly the same as during measurement of the test run (i.e. pressure, flow rates, filter settings on the analysers and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the sample probe. The devices for gas switching shall have a specification to perform the switching in less than 0,1 s. The gases used for the test shall cause a concentration change of at least 60 % full scale (FS).

The concentration trace of each single gas component shall be recorded.

9.1.5.3 System requirements

a) The system response time shall be ≤12,5 s with a rise time of ≤5 s or with a rise and fall time of ≤5 s each for all measured components (CO, NO_x, CO_2 and HC) and all ranges used. When using a NMC for the measurement of NMHC, the system response time may exceed 12,5 s.

   All data (concentration, fuel and air flows) have to be shifted by their measured response times before performing the emission calculations given in ISO 8178-4:2020, Clause 9 and Annex H.

b) To demonstrate acceptable updating and recording with respect to the system's overall response, the system shall meet one of the following criteria:

   1) The product of the mean rise time and the frequency at which the system records an updated concentration shall be at least 5. In any case the mean rise time shall be no more than 10 s;

   2) The frequency at which the system records the concentration shall be at least 2 Hz (see also Table 4).

9.1.5.4 Procedure

The following procedure shall be used to verify the response of each continuous gas analyser system:

a) The analyser system manufacturer's start-up and operating instructions for the instrument setup shall be followed. The measurement system shall be adjusted as needed to optimize performance. This verification shall be run with the analyser operating in the same manner as used for emission testing. If the analyser shares its sampling system with other analysers, and if gas flow to the other analysers will affect the system response time, then the other analysers shall be started up and operated while running this verification test. This verification test may be run on multiple analysers sharing the same sampling system at the same time. If analogue or real-time digital filters are used during emission testing, those filters shall be operated in the same manner during this verification.

b) For equipment used to validate system response time, minimal gas transfer tube lengths between all connections should be used, a zero gas source shall be connected to one inlet of a fast-acting 3-way valve (2 inlets, 1 outlet) in order to control the flow of zero and blended span gases to the sample system's probe inlet or a tee near the outlet of the probe. Normally the gas flow rate is higher than the probe sample flow rate and the excess is overflowed out of the inlet of the probe. If the gas flow rate is lower than the probe flow rate, the gas concentrations shall be adjusted to account for the dilution from ambient air drawn into the probe. Binary or multi-gas span gases may be used. A gas blending or mixing device may be used to blend span gases. A gas blending or mixing device should be applied when blending span gases diluted in N_2 with span gases diluted in air.

   Using a gas divider, an $NO–CO–CO_2–C_3H_8–CH_4$ (balance N_2) span gas shall be equally blended with a span gas of NO_2, balance purified air. Standard binary span gases may also be used, where applicable, in place of blended $NO\text{-}CO\text{-}CO_2\text{-}C_3H_8\text{-}CH_4$, balance N_2 span gas; in this case separate response tests shall be run for each analyser. The gas divider outlet shall be connected to the other inlet of the 3-way valve. The valve outlet shall be connected to an overflow at the gas analyser system's probe or to an overflow fitting between the probe and transfer tube to all the analysers being verified. A setup that avoids pressure pulsations due to stopping the flow through the gas blending device shall be used. Any of these gas constituents if they are not relevant to the analysers for this verification shall be omitted. Alternatively, the use of gas bottles with single gases and a separate measurement of response times is allowed;

c) Data collection shall be done as follows:

   1) The valve shall be switched to start the flow of zero gas.

   2) Stabilization shall be allowed for, accounting for transport delays and the slowest analyser's full response.

3) Data recording shall be started at the frequency used during emission testing. Each recorded value shall be a unique updated concentration measured by the analyser; interpolation or filtering may not be used to alter recorded values.

4) The valve shall be switched to allow the blended span gases to flow to the analysers. This time shall be recorded as t_0.

5) Transport delays and the slowest analyser's full response shall be allowed for.

6) The flow shall be switched to allow zero gas to flow to the analyser. This time shall be recorded as t_{100}.

7) Transport delays and the slowest analyser's full response shall be allowed for.

8) The steps in c) 4) through 7) of this subclause shall be repeated to record seven full cycles, ending with zero gas flowing to the analysers.

9) Recording shall be stopped.

9.1.5.5 Performance evaluation

The data from 9.1.5.4 c) shall be used to calculate the mean rise time, t_{10-90} for each of the analysers.

a) If it is chosen to demonstrate compliance with 9.1.5.3 b) 1) the following procedure has to be applied: The rise times (in s) shall be multiplied by their respective recording frequencies in Hertz (1/s). The value for each result shall be at least 5. If the value is less than 5, the recording frequency shall be increased or the flows adjusted or the design of the sampling system shall be changed to increase the rise time as needed. Also digital filters may be configured to increase rise time.

b) If it is chosen to demonstrate compliance with 9.1.5.3 b) 2), the demonstration of compliance with the requirements of 9.1.5.3 b) 2) is sufficient.

9.1.6 Response time verification for compensation type analysers

9.1.6.1 Scope and frequency

This verification shall be performed to determine a continuous gas analyser's response, where one analyser's response is compensated by another's to quantify a gaseous emission. For this check water vapour shall be considered to be a gaseous constituent. This verification is required for continuous gas analysers used for transient or ramped-modal testing. This verification is not needed for batch gas analysers or for continuous gas analysers that are used only for discrete-mode testing. This verification does not apply to correction for water removed from the sample done in post-processing and it does not apply to NMHC determination from THC and CH_4 quoted in ISO 8178-4:2020, Clause 9 and Annex H. concerning the emission calculations. This verification shall be performed after initial installation (i.e. test cell commissioning). After major maintenance, 9.1.5 may be used to verify uniform response provided that any replaced components have gone through a humidified uniform response verification at some point.

9.1.6.2 Measurement principles

This procedure verifies the time-alignment and uniform response of continuously combined gas measurements. For this procedure, it is necessary to ensure that all compensation algorithms and humidity corrections are turned on.

9.1.6.3 System requirements

The general response time and rise time requirement given in 9.1.5.3 a) is also valid for compensation type analysers. Additionally, if the recording frequency is different than the update frequency of the continuously combined/compensated signal, the lower of these two frequencies shall be used for the verification required by 9.1.5.3 b) 1).

9.1.6.4 Procedure

All procedures given in 9.1.5.4 a) to c) have to be used. Additionally, also the response and rise time of water vapour has to be measured, if a compensation algorithm based on measured water vapour is used. In this case at least one of the used calibration gases (but not NO_2) has to be humidified as follows:

If the system does not use a sample dryer to remove water from the sample gas, the span gas shall be humidified by flowing the gas mixture through a sealed vessel that humidifies the gas to the highest sample dew point that is estimated during emission sampling by bubbling it through distilled water. If the system uses a sample dryer during testing that has passed the sample dryer verification check, the humidified gas mixture may be introduced downstream of the sample dryer by bubbling it through distilled water in a sealed vessel at (25 ± 10) °C, or a temperature greater than the dew point. In all cases, downstream of the vessel, the humidified gas shall be maintained at a temperature of at least 5 ºC above its local dew point in the line. Note that it is possible to omit any of these gas constituents if they are not relevant to the analysers for this verification. If any of the gas constituents are not susceptible to water compensation, the response check for these analysers may be performed without humidification.

9.2 Analytical gases

9.2.1 General

Analytical gases shall meet the accuracy and purity specifications of this subclause.

9.2.2 Gas specifications

The following gas specifications shall be considered:

a) Purified gases shall be used to zero measurement instruments and to blend with calibration gases. Gases with contamination no higher than the highest of the following values in the gas cylinder or at the outlet of a zero-gas generator shall be used:

   1) 2 % contamination, measured relative to the flow-weighted mean concentration expected at the standard. For example, if a CO concentration of 100,0 µmol/mol is expected, then it would be allowed to use a zero gas with CO contamination less than or equal to 2,000 µmol/mol.

   2) Contamination as specified in Table 8, applicable for raw or dilute measurements.

Table 8 — Contamination limits, applicable for raw or dilute measurements [µmol/mol = ppm]

Constituent	Purified air[a]	Purified N_2[a]
THC (C_1 equivalent)	≤0,05 µmol/mol	≤0,05 µmol/mol
CO	≤1 µmol/mol	≤1 µmol/mol
CO_2	≤10 µmol/mol	≤10 µmol/mol
O_2	0,205 to 0,215 mol/mol	≤2 µmol/mol
NO_x	≤0,02 µmol/mol	≤0,02 µmol/mol

[a] It is not required that these levels of purity are international and/or national recognized standards-traceable.

   3) Contamination as specified in Table 9, applicable for raw measurements.

Table 9 — Contamination limits applicable for raw measurements [µmol/mol = ppm]

Constituent	Purified air[a]	Purified N_2[a]
THC (C_1 equivalent)	≤1 µmol/mol	≤1 µmol/mol
CO	≤1 µmol/mol	≤1 µmol/mol
CO_2	≤400 µmol/mol	≤400 µmol/mol
O_2	0,18 to 0,21 mol/mol	—
NO_x	≤0,1 µmol/mol	≤0,1 µmol/mol

[a] It is not required that these levels of purity are international and/or national recognized standards-traceable.

b) The following gases shall be used with a FID analyser:

1) FID fuel shall be used with an H_2 concentration of (0,39 to 0,41) mol/mol, balance He or N_2. The mixture shall not contain more than 0,05 µmol/mol THC.

2) FID burner air shall be used that meets the specifications of purified air in a) of this subclause.

3) FID zero gas. Flame-ionization detectors shall be zeroed with purified gas that meets the specifications in a) of this subclause, except that the purified gas O_2 concentration may be any value.

FID zero balance gases may be any combination of purified air and purified nitrogen. FID analyser zero gases should be used that contain approximately the flow-weighted mean concentration of O_2 expected during testing.

4) FID propane span gas. The THC FID shall be spanned and calibrated with span concentrations of propane, C_3H_8. It shall be calibrated on a carbon number basis of one (C1). For example, if a C_3H_8 span gas of concentration 200 µmol/mol is used, then a FID is recommended to be spanned to respond with a value of 600 µmol/mol.

FID span balance gases may be any combination of purified air and purified nitrogen. FID analyser span gases should contain approximately the flow-weighted mean concentration of O_2 expected during testing.

5) FID methane span gas. If a CH_4 FID is always spanned and calibrated with a non-methane cutter, then the FID shall be spanned and calibrated with span concentrations of methane, CH_4. It shall be calibrated on a carbon number basis of one (C1). For example, if a CH_4 span gas of concentration 200 µmol/mol is used, a FID is recommended to be spanned to respond with a value of 200 µmol/mol.

FID span balance gases may be any combination of purified air and purified nitrogen. FID analyser span gases should contain approximately the flow-weighted mean concentration of O_2 expected during testing.

c) The following gas mixtures shall be used, with gases traceable within ±1,0 % of the international and/or national recognized standards true value or of other gas standards that are approved:

1) CH_4, balance purified air and/or N_2 (as applicable);

2) C_2H_6, balance purified air and/or N_2 (as applicable);

3) C_3H_8, balance purified air and/or N_2 (as applicable);

4) CO, balance purified N_2;

5) CO_2, balance purified N_2;

6) NO, balance purified N_2;

7) NO_2, balance purified air;

    8) O_2, balance purified N_2;

    9) C_3H_8, CO, CO_2, NO, balance purified N_2;

    10) C_3H_8, CH_4, CO, CO_2, NO, balance purified N_2.

d) Gases for species other than those listed in c) of this subclause may be used (such as methanol in air, which may be used to determine response factors), as long as they are traceable to within ±3,0 % of the international and/or national recognized standards true value, and the expiration date has not yet expired.

e) Own calibration gases may be generated using a precision blending device, such as a gas divider, to dilute gases with purified N_2 or purified air. If the gas dividers meet the specifications in 9.2.3, and the gases being blended meet the requirements of a) and c) of this subclause, the resulting blends are considered to meet the requirements of 9.2.2.

9.2.3 Concentration and expiration date

The concentration of any calibration gas standard and its expiration date specified by the gas supplier shall be recorded.

a) No calibration gas standard may be used after its expiration date, except as allowed by b).

b) Calibration gases may be relabelled and used after their expiration date if it is approved in advance by the type approval or certification authority.

9.2.4 Gas transfer

Gases shall be transferred from their source to analysers using components that are dedicated to controlling and transferring only those gases. The shelf life of all calibration gases shall be respected. The expiration date of the calibration gases stated by the manufacturer shall be recorded.

9.3 Vacuum-side leak verification

9.3.1 Scope and frequency

Upon initial sampling system installation, after major maintenance such as pre-filter changes, and within 8 hours prior to each duty-cycle sequence, it shall be verified that there are no significant vacuum-side leaks using one of the leak tests described in this subclause. This verification does not apply to any full-flow portion of a CVS dilution system.

9.3.2 Measurement principles

A leak may be detected either by measuring a small amount of flow when there shall be zero flow, by detecting the dilution of a known concentration of span gas when it flows through the vacuum side of a sampling system or by measuring the pressure increase of an evacuated system.

9.3.3 Low-flow leak test

A sampling system shall be tested for low-flow leaks as follows:

a) The probe end of the system shall be sealed by taking one of the following steps:

    1) The end of the sample probe shall be capped or plugged.

    2) The transfer tube shall be disconnected at the probe and the transfer tube capped or plugged.

   3) A leak-tight valve in-line between a probe and transfer tube shall be closed.

b) All vacuum pumps shall be operated. After stabilizing, it shall be verified that the flow through the vacuum-side of the sampling system is less than 0,5 % of the system's normal in-use flow rate. Typical analyser and bypass flows may be estimated as an approximation of the system's normal in-use flow rate.

9.3.4 Dilution-of-span-gas leak test

Any gas analyser may be used for this test. If a FID is used for this test, any HC contamination in the sampling system shall be corrected according to ISO 8178-4:2020, Clause 9 and Annex H on HC and NMHC determination. Misleading results shall be avoided by using only analysers that have a repeatability of 0,5 % or better at the span gas concentration used for this test. The vacuum side leak check shall be performed as follows:

a) A gas analyser shall be prepared as it would be for emission testing.

b) Span gas shall be supplied to the analyser port and it shall be verified that the span gas concentration is measured within its expected measurement accuracy and repeatability.

c) Overflow span gas shall be routed to one of the following locations in the sampling system:

   1) the end of the sample probe;

   2) the transfer tube shall be disconnected at the probe connection, and the span gas overflown at the open end of the transfer tube;

   3) a three-way valve installed in-line between a probe and its transfer tube.

d) It shall be verified that the measured overflow span gas concentration is within ±0,5 % of the span gas concentration. A measured value lower than expected indicates a leak, but a value higher than expected may indicate a problem with the span gas or the analyser itself. A measured value higher than expected does not indicate a leak.

9.3.5 Vacuum-decay leak test

To perform this test a vacuum shall be applied to the vacuum-side volume of the sampling system and the leak rate of the system shall be observed as a decay in the applied vacuum. To perform this test the vacuum-side volume of the sampling system shall be known to within ±10 % of its true volume. For this test measurement instruments that meet the specifications of 5.3, 6.4, 7.3 and 9.1 shall also be used.

A vacuum-decay leak test shall be performed as follows:

a) The probe end of the system shall be sealed as close to the probe opening as possible by taking one of the following steps:

   1) The end of the sample probe shall be capped or plugged.

   2) The transfer tube at the probe shall be disconnected and the transfer tube capped or plugged.

   3) A leak-tight valve in-line between a probe and transfer tube shall be closed.

b) All vacuum pumps shall be operated. A vacuum shall be drawn that is representative of normal operating conditions. In the case of sample bags, the normal sample bag pump-down procedure should be repeated twice to minimize any trapped volumes.

c) The sample pumps shall be turned off and the system sealed. The absolute pressure of the trapped gas and optionally the system absolute temperature shall be measured and recorded. Sufficient time shall be allowed for any transients to settle and long enough for a leak at 0,5 % to have caused a pressure change of at least 10 times the resolution of the pressure transducer. The pressure and optionally temperature shall be recorded once again.

d) The leak flow rate based on an assumed value of zero for pumped-down bag volumes and based on known values for the sample system volume, the initial and final pressures, optional temperatures, and elapsed time shall be calculated. It shall be verified that the vacuum-decay leak flow rate is less than 0,5 % of the system's normal in-use flow rate as follows:

$$q_{\text{Vleak}} = \frac{V\text{vac}}{R} \frac{\left(\frac{p_2}{T_2} - \frac{p_1}{T}\right)}{(t_2 - t_1)} \qquad (5)$$

where

q_{Vleak} is vacuum-decay leak rate [mol/s];

V_{vac} is geometric volume of the vacuum-side of the sampling system [m^3];

R is molar gas constant [J/(mol K)];

p_2 is vacuum-side absolute pressure at time t_2 [Pa];

T_2 is vacuum-side absolute temperature at time t_2 [K];

p_1 is vacuum-side absolute pressure at time t_1 [Pa];

T_1 is vacuum-side absolute temperature at time t_1 [K];

t_2 is time at completion of vacuum-decay leak verification test [s];

t_1 is time at start of vacuum-decay leak verification test [s].

9.4 NO_2-to-NO converter conversion verification

9.4.1 Scope and frequency

If an analyser is used that measures only NO to determine NO_x, an NO_2-to-NO converter shall be used upstream of the analyser. This verification shall be performed after installing the converter, after major maintenance and within 35 days before an emission test. This verification shall be repeated at this frequency to verify that the catalytic activity of the NO_2-to-NO converter has not deteriorated.

9.4.2 Measurement principles

An NO_2-to-NO converter allows an analyser that measures only NO to determine total NO_x by converting the NO_2 in exhaust to NO.

9.4.3 System requirements

An NO_2-to-NO converter shall allow for measuring at least 95 % of the total NO_2 at the maximum expected concentration of NO_2.

9.4.4 Procedure

The following procedure shall be used to verify the performance of a NO_2-to-NO converter:

a) For the instrument setup the analyser and NO_2-to-NO converter manufacturers' start-up and operating instructions shall be followed. The analyser and converter shall be adjusted as needed to optimize performance.

b) An ozonator's inlet shall be connected to a purified air or oxygen source and its outlet shall be connected to one port of a 3-way tee fitting. An NO span gas shall be connected to another port and the NO_2-to-NO converter inlet shall be connected to the last port.

c) The following steps shall be taken when performing this check:

   1) The ozonator air shall be set off and the ozonator power shall be turned off and the NO_2-to-NO converter shall be set to the bypass mode (i.e., NO mode). Stabilization shall be allowed for, accounting only for transport delays and instrument response.

   2) The NO and zero-gas flows shall be adjusted so the NO concentration at the analyser is near the peak total NO_x concentration expected during testing. The NO_2 content of the gas mixture shall be less than 5 % of the NO concentration. The concentration of NO shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as x_{NOref}. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO concentration is lower than the minimum range for the verification specified by the instrument manufacturer.

   3) The ozonator O_2 supply shall be turned on and the O_2 flow rate adjusted so that the NO indicated by the analyser is about 10 % less than x_{NOref}. The concentration of NO shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value recorded as $x_{\text{NO+O2mix}}$.

   4) The ozonator shall be switched on and the ozone generation rate adjusted so that the NO measured by the analyser is approximately 20 % of x_{NOref}, while maintaining at least 10 % unreacted NO. The concentration of NO shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as x_{NOmeas}.

   5) The NO_x analyser shall be switched to NO_x mode and total NO_x measured. The concentration of NO_x shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as x_{NOxmeas}.

   6) The ozonator shall be switched off but gas flow through the system shall be maintained. The NO_x analyser will indicate the NO_x in the NO + O_2 mixture. The concentration of NO_x shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as $x_{\text{NOx+O2mix}}$.

   7) O_2 supply shall be turned off. The NO_x analyser will indicate the NO_x in the original NO-in-N_2 mixture. The concentration of NO_x shall be recorded by calculating the mean of 30 s of sampled data from the analyser and this value shall be recorded as x_{NOxref}. This value shall be no more than 5 % above the x_{NOref} value.

d) Performance evaluation. The efficiency of the NO_x converter shall be calculated by substituting the concentrations obtained into the following Formula:

$$E_{\text{NOx}}\,[\%] = \left(1 + \frac{x_{\text{NOx,meas}} - x_{\text{NOx}} + \text{O}_{\text{2mix}}}{x_{\text{NO}} + \text{O}_{\text{2mix}} - x_{\text{NOmeas}}}\right) * 100 \tag{6}$$

e) If the result is less than 95 %, the NO_2-to-NO converter shall be repaired or replaced.

9.5 Calibration and set up of gaseous measurements

9.5.1 Scope and frequency

For all FID analysers, the FID shall be calibrated upon initial installation. The calibration shall be repeated as needed using good engineering judgment. The following steps shall be performed for a FID that measures HC:

a) A FID's response to various hydrocarbons shall be optimized after initial analyser installation and after major maintenance. FID response to propylene and toluene shall be between 0,9 and 1,1 relative to propane.

b) A FID's methane (CH_4) response factor shall be determined after initial analyser installation and after major maintenance as described in 9.5.4.

c) Methane (CH_4) response shall be verified within 185 days before testing.

9.5.2 Calibration

Good engineering judgment shall be used to develop a calibration procedure, such as one based on the FID-analyser manufacturer's instructions and recommended frequency for calibrating the FID. For a FID that measures HC, it shall be calibrated using C_3H_8 calibration gases that meet the specifications of 9.2. For a FID that measures CH_4, it shall be calibrated using CH_4 calibration gases that meet the specifications of 9.2. Regardless of the calibration gas composition, it shall be calibrated on a carbon number basis of one (C1).

9.5.3 HC FID response optimization

This procedure is only for FID analysers that measure HC.

a) Instrument manufacturer requirements and good engineering judgment shall be used for initial instrument start-up and basic operating adjustment using FID fuel and purified air. Heated FIDs shall be within their required operating temperature ranges. FID response shall be optimized to meet the requirement of the hydrocarbon response factors and the oxygen interference check according to 9.5 and 9.5.6 at the most common analyser range expected during emission testing. Higher analyser range may be used according to the instrument manufacturer's recommendation and good engineering judgment in order to optimize FID accurately, if the common analyser range is lower than the minimum range for the optimization specified by the instrument manufacturer.

b) Heated FIDs shall be within their required operating temperature ranges. FID response shall be optimized at the most common analyser range expected during emission testing. With the fuel and airflow rates set at the manufacturer's recommendations, a span gas shall be introduced to the analyser.

c) The following step from 1) to 4) or the procedure instructed by the instrument manufacturer shall be taken for optimization. The procedures outlined in SAE paper No. 770141 may be optionally used for optimization:

    1) The response at a given fuel flow shall be determined from the difference between the span gas response and the zero gas response.

    2) The fuel flow shall be incrementally adjusted above and below the manufacturer's specification. The span and zero response at these fuel flows shall be recorded.

    3) The difference between the span and zero response shall be plotted and the fuel flow adjusted to the rich side of the curve. This is the initial flow rate setting which may need further optimization depending on the results of the hydrocarbon response factors and the oxygen interference check according to 9.5 and 9.5.6.

    4) If the oxygen interference or the hydrocarbon response factors do not meet the following specifications, the airflow shall be incrementally adjusted above and below the manufacturer's specifications, repeating 9.5 and 9.5.6 for each flow.

d) The optimum flow rates and/or pressures for FID fuel and burner air shall be determined, and they shall be sampled and recorded for future reference.

9.5.4 HC FID CH_4 response factor determination

This procedure is only for FID analysers that measure THC. Since FID analysers generally have a different response to CH_4 versus C_3H_8, each THC FID analyser's CH_4 response factor, $f_{\text{RF CH4[THC-FID]}}$ shall be determined, after FID optimization. The most recent $f_{\text{RF CH4[THC-FID]}}$ measured according to this subclause shall be used in the calculations for HC determination described in ISO 8178-4:2020, Annex H (molar based approach) or ISO 8178-4:2020, Clause 9 (mass based approach) to compensate for CH_4 response. $f_{RF\ CH4[THC\text{-}FID]}$ shall be determined as follows, noting that $f_{RF\ CH4[THC\text{-}FID]}$ is not determined for FIDs that are calibrated and spanned using CH_4 with a non-methane cutter:

a) A C_3H_8 span gas concentration shall be selected to span the analyser before emission testing. Only span gases that meets the specifications of 9.2 shall be selected and the C_3H_8 concentration of the gas shall be recorded.

b) A CH_4 span gas that meets the specifications of 9.2 shall be selected and the CH_4 concentration of the gas shall be recorded.

c) The FID analyser shall be operated according to the manufacturer's instructions.

d) It shall be confirmed that the FID analyser has been calibrated using C_3H_8. Calibration shall be performed on a carbon number basis of one (C_1).

e) The FID shall be zeroed with a zero gas used for emission testing.

f) The FID shall be spanned with the selected C_3H_8 span gas.

g) The selected CH_4 span gas shall be introduced at the sample port of the FID analyser, the CH_4 span gas that has been selected under b) of this subclause.

h) The analyser response shall be stabilized. Stabilization time may include time to purge the analyser and to account for its response.

i) While the analyser measures the CH_4 concentration, 30 s of sampled data shall be recorded and the arithmetic mean of these values shall be calculated.

j) The mean measured concentration shall be divided by the recorded span concentration of the CH_4 calibration gas. The result is the FID analyser's response factor for CH_4, $f_{RF\ CH4[THC\text{-}FID]}$.

9.5.5 HC FID methane (CH_4) response verification

This procedure is only for FID analysers that measure HC. If the value of $f_{RF\ CH4[THC\text{-}FID]}$ from 9.5.4 is within ±5,0 % of its most recent previously determined value, the HC FID passes the methane response verification.

a) It shall be first verified that the pressures and/or flow rates of FID fuel, burner air, and sample are each within ±0,5 % their most recent previously recorded values, as described in 9.5.3. If these flow rates have to be adjusted, a new $f_{RF\ CH4[THC\text{-}FID]}$ shall be determined as described in 9.5.4. It should be verified that the value of $f_{RF\ CH4[THC\text{-}FID]}$ determined is within the tolerance specified in 9.5.5.

b) If $f_{RF\ CH4[THC\text{-}FID]}$ is not within the tolerance specified in 9.5.5, the FID response shall be re-optimized as described in 9.5.3.

c) A new $f_{RF\ CH4[THC\text{-}FID]}$ shall be determined as described in 9.5.4. This new value of $f_{RF\ CH4[THC\text{-}FID]}$ shall be used in the calculations for HC determination, as described in ISO 8178-4:2020, Annex H (molar based approach) or Clause 9 (mass based approach).

9.5.6 Non-stoichiometric raw exhaust FID O_2 interference verification

9.5.6.1 Scope and frequency

If FID analysers are used for raw exhaust measurements, the amount of FID O_2 interference shall be verified upon initial installation and after major maintenance.

9.5.6.2 Measurement principles

Changes in O_2 concentration in raw exhaust can affect FID response by changing FID flame temperature. FID fuel, burner air, and sample flow shall be optimized to meet this verification. FID performance shall be verified with the compensation algorithms for FID O_2 interference that is active during an emission test.

9.5.6.3 System requirements

Any FID analyser used during testing shall meet the FID O_2 interference verification according to the procedure in this subclause.

9.5.6.4 Procedure

FID O_2 interference shall be determined as follows, noting that one or more gas dividers may be used to create reference gas concentrations that are required to perform this verification:

a) Three span reference gases shall be selected that meet the specifications in 9.2 and contain C_3H_8 concentration used to span the analysers before emissions testing. CH_4 span reference gases may be used for FIDs calibrated on CH_4 with a non-methane cutter. The three balance gas concentrations shall be selected such that the concentrations of O_2 and N_2 represent the minimum and maximum and intermediate O_2 concentrations expected during testing. The requirement for using the average O_2 concentration can be removed if the FID is calibrated with span gas balanced with the average expected oxygen concentration.

b) It shall be confirmed that the FID analyser meets all the specifications of 9.5.

c) The FID analyser shall be started and operated as it would be before an emission test. Regardless of the FID burner's air source during testing, purified air shall be used as the FID burner's air source for this verification.

d) The analyser shall be set at zero.

e) The analyser shall be spanned using a span gas that is used during emissions testing.

f) The zero response shall be checked by using the zero gas used during emission testing. It shall be proceeded to the next step if the mean zero response of 30 s of sampled data is within ±0,5 % of the span reference value used in e) of this subclause, otherwise the procedure shall be restarted at d) of this subclause.

g) The analyser response shall be checked using the span gas that has the minimum concentration of O_2 expected during testing. The mean response of 30 s of stabilized sample data shall be recorded as x_{O2minHC}.

h) The zero response of the FID analyser shall be checked using the zero gas used during emission testing. The next step shall be performed if the mean zero response of 30 s of stabilized sample data is within ±0,5 % of the span reference value used in e) of this subclause, otherwise the procedure shall be restarted at paragraph d) of this subclause.

i) The analyser response shall be checked using the span gas that has the average concentration of O_2 expected during testing. The mean response of 30 s of stabilized sample data shall be recorded as x_{O2avgHC}.

j) The zero response of the FID analyser shall be checked using the zero gas used during emission testing. The next step shall be performed if the mean zero response of 30 s of stabilized sample data is within ±0,5 % of the span reference value used in e) of this subclause, otherwise the procedure shall be restarted at d) of this subclause.

k) The analyser response shall be checked using the span gas that has the maximum concentration of O_2 expected during testing. The mean response of 30 s of stabilized sample data shall be recorded as x_{O2maxHC}.

l) The zero response of the FID analyser shall be checked using the zero gas used during emission testing. The next step shall be performed if the mean zero response of 30 s of stabilized sample data is within ±0,5 % of the span reference value used in e) of this subclause, otherwise the procedure at d) of this subclause shall be restarted.

m) The % difference between $x_{O2maxHC}$ and its reference gas concentration shall be calculated. The % difference between $x_{O2avgHC}$ and its reference gas concentration shall be calculated. The % difference between $x_{O2minHC}$ and its reference gas concentration shall be calculated. The maximum % difference of the three shall be determined. This is the O_2 interference.

n) If the O_2 interference is within ±3 %, the FID passes the O_2 interference verification; otherwise one or more of the following need to be performed to address the deficiency:

   1) The verification shall be repeated to determine if a mistake was made during the procedure.

   2) The zero and span gases for emission testing shall be selected that contain higher or lower O_2 concentrations and the verification shall be repeated.

   3) The FID burner air, fuel, and sample flow rates shall be adjusted. Note that if these flow rates are adjusted on a THC FID to meet the O_2 interference verification, the $f_{RF\ CH4}$ shall be reset for the next $f_{RF\ CH4}$ verification. The O_2 interference verification shall be repeated after adjustment and $f_{RF\ CH4}$ shall be determined.

   4) The FID shall be repaired or replaced and the O_2 interference verification shall be repeated.

9.5.7 Efficiency of the Non-Methane Cutter (NMC)

9.5.7.1 Scope and frequency

If a FID analyser and a non-methane cutter (NMC) is used to measure methane (CH_4), the non-methane cutter's conversion efficiencies of methane, E_{CH4}, and ethane, E_{C2H6} shall be determined. As detailed in this subclause, these conversion efficiencies may be determined as a combination of NMC conversion efficiencies and FID analyser response factors, depending on the particular NMC and FID analyser configuration.

This verification shall be performed after installing the non-methane cutter. This verification shall be repeated within 185 days of testing to verify that the catalytic activity of the cutter has not deteriorated.

9.5.7.2 Measurement principles

A non-methane cutter is a heated catalyst that removes non-methane hydrocarbons from the exhaust sample before the FID analyser measures the remaining hydrocarbon concentration. An ideal non-methane cutter would have a methane conversion efficiency E_{CH4} [-] of 0 (that is, a methane penetration fraction, $f_{PF\ CH4}$, of 1,000), and the conversion efficiency for all other hydrocarbons would be 1,000, as represented by an ethane conversion efficiency E_{C2H6} [-] of 1 (that is, an ethane penetration fraction $f_{PF\ C2H6}$ [-] of 0). The emission calculations in ISO 8178-4:2020, Clause 9 or Annex H use this subclause's measured values of conversion efficiencies E_{CH4} and E_{C2H6} to account for less than ideal NMC performance.

9.5.7.3 System requirements

NMC conversion efficiencies are not limited to a certain range. However, a non-methane cutter should be optimized by adjusting its temperature to achieve a $E_{CH4} < 0{,}15$ and a $E_{C2H6} > 0{,}98$ ($f_{PF\ CH4} > 0{,}85$ and $f_{PF\ C2H6} < 0{,}02$) as determined by 9.5.7.4, as applicable. If adjusting NMC temperature does not result in achieving these specifications, the catalyst material should be replaced. The most recently determined conversion values from this subclause shall be used to calculate HC emissions according to ISO 8178-4:2020, Clause 9 or Annex H as applicable.

9.5.7.4 Procedure

Any one of the procedures specified in 9.5.7.4.1, 9.5.7.4.2 and 9.5.7.4.3 should be applied. An alternative method recommended by the instrument manufacturer may be used.

9.5.7.4.1 Procedure for a FID calibrated with the NMC

If a FID is always calibrated to measure CH_4 with the NMC, then the FID shall be spanned with the NMC using a CH_4 span gas, the product of that FID's CH_4 response factor and CH_4 penetration fraction, $f_{\mathrm{RFPF\ CH4[NMC\text{-}FID]}}$, shall be set equal to 1,0 (i.e. efficiency E_{CH4} [-] is set to 0) for all emission calculations, and the combined ethane (C_2H_6) response factor and penetration fraction, $f_{\mathrm{RFPF\ C2H6[NMC\text{-}FID]}}$ (and efficiency E_{C2H6} [-]) shall be determined as follows:

a) Both a CH_4 gas mixture and a C_2H_6 analytical gas mixture shall be selected meeting the specifications of 9.2. Both a CH_4 concentration for spanning the FID during emission testing and a C_2H_6 concentration that is typical of the peak NMHC concentration expected at the hydrocarbon standard or equal to THC analyser's span value shall be selected.

b) The non-methane cutter shall be started, operated, and optimized according to the manufacturer's instructions, including any temperature optimization.

c) It shall be confirmed that the FID analyser meets all the specifications of 9.5.

d) The FID analyser shall be operated according to the manufacturer's instructions.

e) CH_4 span gas shall be used to span the FID with the cutter. The FID shall be spanned on a C_1 basis. For example, if the span gas has a CH_4 reference value of 100 µmol/mol, the correct FID response to that span gas is 100 µmol/mol because there is one carbon atom per CH_4 molecule.

f) The C_2H_6 analytical gas mixture shall be introduced upstream of the non-methane cutter.

g) The analyser response shall be stabilized. Stabilization time may include time to purge the non-methane cutter and to account for the analyser's response.

h) While the analyser measures a stable concentration, 30 s of sampled data shall be recorded and the arithmetic mean of these data points shall be calculated.

i) The mean shall be divided by the reference value of C_2H_6, converted to a C1 basis. The result is the C_2H_6 combined response factor and penetration fraction, $f_{\mathrm{RFPF\ C2H6[NMC\text{-}FID]}}$, equivalent to $(1 - E_{\mathrm{C2H6}}$ [-]). This combined response factor and penetration fraction and the product of the CH_4 response factor and CH_4 penetration fraction, $f_{\mathrm{RFPF\ CH4[NMC\text{-}FID]}}$, which is set equal to 1,0, in emission calculations shall be used according to ISO 8178-4:2020, Clause 9 or Annex H as applicable.

9.5.7.4.2 Procedure for a FID calibrated with propane bypassing the NMC

If a FID is used with an NMC that is calibrated with propane, C_3H_8, by bypassing the NMC, penetrations fractions $f_{\mathrm{PF\ C2H6[NMC\text{-}FID]}}$ and $f_{\mathrm{PF\ CH4[NMC\text{-}FID]}}$ shall be determined as follows:

a) A CH_4 gas mixture and a C_2H_6 analytical gas mixture shall be selected meeting the specifications of 9.2 with the CH_4 concentration typical of its peak concentration expected at the hydrocarbon standard and the C_2H_6 concentration typical of the peak total hydrocarbon (THC) concentration expected at the hydrocarbon standard or the THC analyser span value.

b) The non-methane cutter shall be started and operated according to the manufacturer's instructions, including any temperature optimization.

c) It shall be confirmed that the FID analyser meets all the specifications of 9.5.

d) The FID analyser shall be operated according to the manufacturer's instructions.

e) The FID shall be zeroed and spanned as it would be during emission testing. The FID shall be spanned by bypassing the cutter and by using C_3H_8 span gas to span the FID. The FID shall be spanned on a C_1 basis.

f) The C_2H_6 analytical gas mixture shall be introduced upstream of the non-methane cutter at the same point the zero gas was introduced.

g) Time shall be allowed for the analyser response to stabilize. Stabilization time may include time to purge the non-methane cutter and to account for the analyser's response.

h) While the analyser measures a stable concentration, 30 s of sampled data shall be recorded and the arithmetic mean of these data points shall be calculated.

i) The flow path shall be rerouted to bypass the non-methane cutter, the C_2H_6 analytical gas mixture shall be introduced to the bypass, and the steps in g) through h) of this subclause shall be repeated.

j) The mean C_2H_6 concentration measured through the non-methane cutter shall be divided by the flow-weighted mean concentration measured after bypassing the non-methane cutter. The result is the C_2H_6 penetration fraction, $f_{\mathrm{PF\ C2H6[NMC\text{-}FID]}}$, that is equivalent to (1 - E_{C2H6} [-]). This penetration fraction shall be used according to ISO 8178-4:2020, Clause 9 or Annex H, as applicable.

k) The steps in f) through j) of this subclause shall be repeated, but with the CH_4 analytical gas mixture instead of C_2H_6. The result will be the CH_4 penetration fraction, $f_{\mathrm{PF\ CH4[NMC\text{-}FID]}}$ (equivalent to (1 − E_{CH4} [-])). This penetration fraction shall be used according to ISO 8178-4:2020, Clause 9 or Annex H, as applicable.

9.5.7.4.3 Procedure for a FID calibrated with methane, bypassing the NMC

If a FID is used with an NMC that is calibrated with methane, CH_4, by bypassing the NMC, determine its combined ethane (C_2H_6) response factor and penetration fraction, $f_{\mathrm{RFPF\ C2H6[NMC\text{-}FID]}}$, as well as its CH_4 penetration fraction, $f_{\mathrm{PF\ CH4[NMC\text{-}FID]}}$, as follows:

a) CH_4 and C_2H_6 analytical gas mixtures shall be selected that meet the specifications of 9.2, with the CH_4 concentration typical of its peak concentration expected at the hydrocarbon standard and the C_2H_6 concentration typical of the peak total hydrocarbon (THC) concentration expected at the hydrocarbon standard or the THC analyser span value.

b) The non-methane cutter shall be started and operated according to the manufacturer's instructions, including any temperature optimization.

c) It shall be confirmed that the FID analyser meets all the specifications of 9.5.

d) The FID analyser shall be started and operated according to the manufacturer's instructions.

e) The FID shall be zeroed and spanned as it would during emission testing. The FID shall be spanned with CH_4 span gas by bypassing the cutter. Note that the FID shall be spanned on a C1 basis. For example, if the span gas has a methane reference value of 100 µmol/mol, the correct FID response to that span gas is 100 µmol/mol because there is one carbon atom per CH_4 molecule.

f) The C_2H_6 analytical gas mixture shall be introduced upstream of the non-methane cutter at the same point the zero gas was introduced.

g) Time shall be allowed for the analyser response to stabilize. Stabilization time may include time to purge the non-methane cutter and to account for the analyser's response.

h) 30 s of sampled data shall be recorded while the analyser measures a stable concentration. The arithmetic mean of these data points shall be calculated.

i) The flow path to bypass the non-methane cutter shall be rerouted, the C_2H_6 analytical gas mixture shall be introduced to the bypass, and the steps in g) and h) of this subclause shall be repeated.

j) The mean C_2H_6 concentration measured through the non-methane cutter shall be divided by the flow-weighted mean concentration measured after bypassing the non-methane cutter. The result is the C_2H_6 combined response factor and penetration fraction, $f_{\mathrm{RFPF\ C2H6[NMC\text{-}FID]}}$. This combined response factor and penetration fraction shall be used according to ISO 8178-4:2020, Annex H or Clause 9, as applicable.

k) The steps in f) through j) of this subclause shall be repeated, but with the CH_4 analytical gas mixture instead of C_2H_6. The result will be the CH_4 penetration fraction, $f_{\mathrm{PF\ CH4[NMC\text{-}FID]}}$. This penetration fraction shall be used according to ISO 8178-4:2020, Annex H or Clause 9, as applicable.

9.5.8 CO and CO_2 Measurements

9.5.8.1 H_2O interference verification for CO_2 NDIR analysers

9.5.8.1.1 Scope and frequency

If CO_2 is measured using an NDIR analyser, the amount of H_2O interference shall be verified after initial analyser installation and after major maintenance.

9.5.8.1.2 Measurement principles

H_2O can interfere with an NDIR analyser's response to CO_2. If the NDIR analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously these other measurements shall be conducted to test the compensation algorithms during the analyser interference verification.

9.5.8.1.3 System requirements

A CO_2 NDIR analyser shall have an H_2O interference that is within 0,4 mmol/mol of the expected mean CO_2 concentration, though a lower interference that is within 0,2 mmol/mol is recommended.

9.5.8.1.4 Procedure

The interference verification shall be performed as follows:

a) The CO_2 NDIR analyser shall be started, operated, zeroed, and spanned as it would be before an emission test.

b) A humidified test gas shall be created by bubbling zero gas that meets the specifications in 9.2 through distilled water in a sealed vessel. If the sample is not passed through a dryer, control the vessel temperature to generate an H_2O level at least as high as the maximum expected during testing. If the sample is passed through a dryer during testing, control the vessel temperature to generate an H_2O level at least as high as the level determined in 5.2.2.3.1.

c) The humidified test gas temperature shall be maintained at least 5 °C above its dew point downstream of the vessel.

d) The humidified test gas shall be introduced into the sampling system. The humidified test gas may be introduced downstream of any sample dryer, if one is used during testing.

e) The water mole fraction, x_{H2O}, of the humidified test gas shall be measured, as close as possible to the inlet of the analyser. For example, dew point, T_{dew}, and absolute pressure p_{total}, shall be measured to calculate x_{H2O}.

f) Good engineering judgment shall be used to prevent condensation in the transfer tubes, fittings, or valves from the point where x_{H2O} is measured to the analyser.

g) Time shall be allowed for the analyser response to stabilize. Stabilization time shall include time to purge the transfer tube and to account for analyser response.

h) While the analyser measures the sample's concentration, 30 s of sampled data shall be recorded. The arithmetic mean of this data shall be calculated. The analyser meets the interference verification if this value is within 0,4 mmol/mol.

9.5.8.2 H_2O and CO_2 interference verification for CO NDIR analysers

9.5.8.2.1 Scope and frequency

If CO is measured using an NDIR analyser, the amount of H_2O and CO_2 interference shall be verified after initial analyser installation and after major maintenance.

9.5.8.2.2 Measurement principles

H_2O and CO_2 can positively interfere with an NDIR analyser by causing a response similar to CO. If the NDIR analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously these other measurements shall be conducted to test the compensation algorithms during the analyser interference verification.

9.5.8.2.3 System requirements

A CO NDIR analyser shall have combined H_2O and CO_2 interference that is within ±2 % of the expected flow-weighted mean concentration of CO corresponding to the applicable limit specified by the parties concerned.

9.5.8.2.4 Procedure

The interference verification shall be performed as follows:

a) The CO NDIR analyser shall be started, operated, zeroed, and spanned as it would be before an emission test.

b) A humidified CO_2 test gas shall be created by bubbling a CO_2 span gas through distilled water in a sealed vessel. If the sample is not passed through a dryer, the vessel temperature shall be controlled to generate an H_2O level at least as high as the maximum expected during testing. If the sample is passed through a dryer during testing, the vessel temperature shall be controlled to generate an H_2O level at least as high as the level determined in 9.8.5.8. A CO_2 span gas concentration shall be used at least as high as the maximum expected during testing.

c) The humidified CO_2 test gas shall be introduced into the sampling system. The humidified CO_2 test gas may be introduced downstream of any sample dryer, if one is used during testing.

d) The water mole fraction, x_{H2O}, of the humidified test gas shall be measured, as close as possible to the inlet of the analyser. For example, dew point, T_{dew}, and absolute pressure p_{total}, shall be measured to calculate x_{H2O}.

e) Good engineering judgment shall be used to prevent condensation in the transfer tubes, fittings, or valves from the point where x_{H2O} is measured to the analyser.

f) Time shall be allowed for the analyser response to stabilize.

g) While the analyser measures the sample's concentration, its output shall be recorded for 30 s. The arithmetic mean of this data shall be calculated.

h) The analyser meets the interference verification if the result of g) meets the tolerance in 9.5.8.2.3.

i) Interference procedures for CO_2 and H_2O may be also run separately. If the CO_2 and H_2O levels used are higher than the maximum levels expected during testing, each observed interference value shall be scaled down by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. Separate interference procedures concentrations of H_2O (down to 0,025 mol/mol H_2O content) that are lower than the maximum levels expected during testing may be run, but the observed H_2O interference shall be scaled up by multiplying the observed interference by the ratio of the maximum expected H_2O concentration value to the actual value used during this procedure. The sum of the two scaled interference values shall meet the tolerance in 9.5.8.2.3.

9.5.9 NO_x Measurement

9.5.9.1 CLD CO_2 and H_2O quench verification

9.5.9.1.1 Scope and frequency

If a CLD analyser is used to measure NO_x, the amount of H_2O and CO_2 quench shall be verified after installing the CLD analyser and after major maintenance.

9.5.9.1.2 Measurement principles

H_2O and CO_2 can negatively interfere with a CLD's NO_x response by collisional quenching, which inhibits the chemiluminescent reaction that a CLD utilizes to detect NO_x. This procedure and the calculations in 9.5.9.1.6.3 determine quench and scale the quench results to the maximum mole fraction of H_2O and the maximum CO_2 concentration expected during emission testing. If the CLD analyser uses quench compensation algorithms that utilize H_2O and/or CO_2 measurement instruments, quench shall be evaluated with these instruments active and with the compensation algorithms applied.

9.5.9.1.3 System requirements

For raw or dilute measurement a CLD analyser shall not exceed a combined H_2O and CO_2 quench of ±2 %. Combined quench is the sum of the CO_2 quench determined as described in 9.5.9.1.4 and the H_2O quench as determined in 9.5.9.1.5. If these requirements are not met, corrective action shall be taken by repairing or replacing the analyser. Before running emission tests, it shall be verified that the corrective action have successfully restored the analyser to proper functioning.

9.5.9.1.4 CO_2 quench verification procedure

The following method or the method prescribed by the instrument manufacturer may be used to determine CO_2 quench by using a gas divider that blends binary span gases with zero gas as the diluent and meets the specifications in 9.2.3, or good engineering judgment shall be used to develop a different protocol:

a) PTFE or stainless steel tubing shall be used to make necessary connections.

b) The gas divider shall be configured such that nearly equal amounts of the span and diluent gases are blended with each other.

c) If the CLD analyser has an operating mode in which it detects NO-only, as opposed to total NO_x, the CLD analyser shall be operated in the NO-only operating mode.

d) A CO_2 span gas that meets the specifications of 9.2 and a concentration that is approximately twice the maximum CO_2 concentration expected during emission testing shall be used.

e) A NO span gas that meets the specifications of 9.2 and a concentration that is approximately twice the maximum NO concentration expected during emission testing shall be used. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO concentration is lower than the minimum range for the verification specified by the instrument manufacturer.

f) The CLD analyser shall be zeroed and spanned. The CLD analyser shall be spanned with the NO span gas from e) of this subclause through the gas divider. The NO span gas shall be connected to the span port of the gas divider; a zero gas shall be connected to the diluent port of the gas divider; the same nominal blend ratio shall be used as selected in b) of this subclause; and the gas divider's output concentration of NO shall be used to span the CLD analyser. Gas property corrections shall be applied as necessary to ensure accurate gas division.

g) The CO_2 span gas shall be connected to the span port of the gas divider.

h) The NO span gas shall be connected to the diluents port of the gas divider.

i) While flowing NO and CO_2 through the gas divider, the output of the gas divider shall be stabilized. The CO_2 concentration from the gas divider output shall be determined, applying gas property correction as necessary to ensure accurate gas division. This concentration, x_{CO2act}, shall be recorded and it shall be used in the quench verification calculations in 9.5.9.1.6.3. As an alternative to using a gas divider, another simple gas blending device may be used. In this case an analyser shall be used to determine CO_2 concentration. If a NDIR is used together with a simple gas blending device, it shall meet the requirements of this subclause and it shall be spanned with the CO_2 span gas from d). The linearity of the NDIR analyser has to be checked before over the whole range up to twice of the expected maximum CO_2 concentration expected during testing.

j) The NO concentration shall be measured downstream of the gas divider with the CLD analyser. Time shall be allowed for the analyser response to stabilize. Stabilization time may include time to purge the transfer tube and to account for analyser response. While the analyser measures the sample's concentration, the analyser's output shall be recorded for 30 s. The arithmetic mean concentration shall be calculated from these data, x_{NOmeas}. x_{NOmeas} shall be recorded and it shall be used in the quench verification calculations in 9.5.9.1.6.3.

k) The actual NO concentration shall be calculated at the gas divider's outlet, x_{NOact}, based on the span gas concentrations and x_{CO2act} according to Formula (8). The calculated value shall be used in the quench verification calculations in Formula (7).

l) The values recorded according to 9.5.9.1.4 and 9.5.9.1.5 shall be used to calculate quench as described in 9.5.9.1.6.3.

9.5.9.1.5 H_2O quench verification procedure

Except where it can be demonstrated by engineering analysis that the combined CO_2 and H_2O interference for the NO_x CLD analyser always affects the brake-specific NO_x emission results within no more than ±1 % of the applicable NO_x standard for the NO_x sampling system and the emission calculation procedures the following method or the method prescribed by the instrument manufacturer may be used to determine H_2O quench, or good engineering judgment shall be used to develop a different protocol:

a) PTFE or stainless steel tubing shall be used to make necessary connections.

b) If the CLD analyser has an operating mode in which it detects NO-only, as opposed to total NO_x, the CLD analyser shall be operated in the NO-only operating mode.

c) A NO span gas shall be used that meets the specifications of 9.2 and a concentration that is near the maximum concentration expected during emission testing. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO concentration is lower than the minimum range for the verification specified by the instrument manufacturer.

d) The CLD analyser shall be zeroed and spanned. The CLD analyser shall be spanned with the NO span gas from c) of this subclause, the span gas concentration shall be recorded as x_{NOdry}, and it shall be used in the quench verification calculations in 9.5.9.1.6.3.

e) The NO span gas shall be humidified by bubbling it through distilled water in a sealed vessel. If the humidified NO span gas sample does not pass through a sample dryer for this verification test, the vessel temperature shall be controlled to generate an H_2O level approximately equal to the maximum mole fraction of H_2O expected during emission testing. If the humidified NO span gas sample does not pass through a sample dryer, the quench verification calculations in 9.5.9.1.6.3 scale the measured H_2O quench to the highest mole fraction of H_2O expected during emission testing. If the humidified NO span gas sample passes through a dryer for this verification test, the vessel temperature shall be controlled to generate an H_2O level at least as high as the level determined in 5.2.2.3.1. For this case, the quench verification calculations in 9.5.9.1.6.3 do not scale the measured H_2O quench.

f) The humidified NO test gas shall be introduced into the sample system. It may be introduced upstream or downstream of a sample dryer that is used during emission testing. Depending on the point of introduction, the respective calculation method of e) shall be selected. Note that the sample dryer shall meet the sample dryer verification check in 9.8.5.8.

g) The mole fraction of H_2O in the humidified NO span gas shall be measured. In case a sample dryer is used, the mole fraction of H_2O in the humidified NO span gas shall be measured downstream of the sample dryer, x_{H2Omeas}. Measure x_{H2Omeas} as close as possible to the CLD analyser inlet. x_{H2Omeas} may be calculated from measurements of dew point, T_{dew}, and absolute pressure, p_{total}.

h) Good engineering judgment shall be used to prevent condensation in the transfer tubes, fittings, or valves from the point where x_{H2Omeas} is measured to the analyser. The system should be designed so the wall temperatures in the transfer tubes, fittings, and valves from the point where x_{H2Omeas} is measured to the analyser are at least 5 °C above the local sample gas dew point.

i) The humidified NO span gas concentration shall be measured with the CLD analyser. Time shall be allowed for the analyser response to stabilize. Stabilization time may include time to purge the transfer tube and to account for analyser response. While the analyser measures the sample's concentration, the analyser's output shall be recorded for 30 s. The arithmetic mean shall be calculated of these data, x_{NOwet}. x_{NOwet} shall be recorded and used in the quench verification calculations in 9.5.9.1.6.3.

j) A NO_x CLD analyser that does not meet this verification may be used, as long as a correction is applied and the measurement deficiency does not adversely affect the ability to demonstrate that the engine complies with all applicable emission limits.

9.5.9.1.6 CLD quench verification calculations

CLD quench-check calculations shall be performed as described in this subclause.

9.5.9.1.6.1 Amount of water expected during testing

The maximum expected mole fraction of water during emission testing, x_{H2Oexp} shall be estimated. This estimate shall be made where the humidified NO span gas was introduced in 9.5.9.1.5 f). When estimating the maximum expected mole fraction of water, the maximum expected water content in combustion air, fuel combustion products, and dilution air (if applicable) shall be considered. If the humidified NO span gas is introduced into the sample system upstream of a sample dryer during the verification test, it is not needed to estimate the maximum expected mole fraction of water and x_{H2Oexp} shall be set equal to x_{H2Omeas}.

9.5.9.1.6.2 Amount of CO_2 expected during testing

The maximum expected CO_2 concentration during emission testing, x_{CO2exp} shall be estimated. This estimate shall be made at the sample system location where the blended NO and CO_2 span gases are introduced according to 9.5.9.1.4 j). When estimating the maximum expected CO_2 concentration, the maximum expected CO_2 content in fuel combustion products and dilution air shall be considered.

9.5.9.1.6.3 Combined H_2O and CO_2 quench calculations

Combined H_2O and CO_2 quench shall be calculated as follows:

$$E_{\mathrm{CLD}} = \left[\left(\frac{\dfrac{x_{\mathrm{NO_{wet}}}}{1 - x_{\mathrm{H_2Omeas}}}}{x_{\mathrm{NO_{dry}}}} - 1 \right) \times \frac{x_{\mathrm{H_2O\,exp}}}{x_{\mathrm{H_2Omeas}}} + \left(\frac{x_{\mathrm{NO_{meas}}}}{x_{\mathrm{NO_{act}}}} - 1 \right) \times \frac{x_{\mathrm{CO_2,exp}}}{x_{\mathrm{CO_2,act}}} \right] \times 100\% \tag{7}$$

where

E_{CLD}	is amount of CLD quench;
x_{NOdry}	is measured concentration of NO upstream of a bubbler, according to 9.5.9.1.5 d);
x_{NOwet}	is measured concentration of NO downstream of a bubbler, according to 9.5.9.1.5 i);
x_{H2Oexp}	is maximum expected mole fraction of water during emission testing according to 9.5.9.1.6.1;
x_{H2Omeas}	is measured mole fraction of water during the quench verification according to 9.5.9.1.5.g);
x_{NOmeas}	is measured concentration of NO when NO span gas is blended with CO_2 span gas, according to 9.5.9.1.4 j);
x_{NOact}	is actual concentration of NO when NO span gas is blended with CO_2 span gas, according to 9.5.9.1.4 k) and calculated according to Formula (8);
x_{CO2exp}	is maximum expected concentration of CO_2 during emission testing, according to 9.5.9.1.6.2;
x_{CO2act}	is actual concentration of CO_2 when NO span gas is blended with CO_2 span gas, according to 9.5.9.1.4 i).

$$x_{\mathrm{NO_{act}}} = \left(1 - \frac{x_{\mathrm{CO_{2,act}}}}{x_{\mathrm{CO_{2,span}}}} \right) \times x_{\mathrm{NO_{span}}} \tag{8}$$

where

x_{NOspan}	is the NO span gas concentration input to the gas divider, according to 9.5.9.1.4 e);
x_{CO2span}	is the CO_2 span gas concentration input to the gas divider, according to 9.5.9.1.4 d).

9.5.9.2 NDUV analyser HC and H_2O interference verification

9.5.9.2.1 Scope and frequency

If NO_x is measured using an NDUV analyser, the amount of H_2O and hydrocarbon interference shall be verified after initial analyser installation and after major maintenance.

9.5.9.2.2 Measurement principles

Hydrocarbons and H_2O can positively interfere with a NDUV analyser by causing a response similar to NO_x. If the NDUV analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously such measurements shall be conducted to test the algorithms during the analyser interference verification.

9.5.9.2.3 System requirements

A NO_x NDUV analyser shall have combined H_2O and HC interference within ±2 % of the flow-weighted mean concentration of NO_x that would correspond to the applicable limit value.

9.5.9.2.4 Procedure

The interference verification shall be performed as follows:

a) The NO_x NDUV analyser shall be started, operated, zeroed, and spanned according to the instrument manufacturer's instructions.

b) Extract engine exhaust to perform this verification. A CLD shall be used that meets the specifications of Clauses 5.3, 6 and 7.3 to quantify NO_x in the exhaust. The CLD response shall be used as the reference value. Also HC shall be measured in the exhaust with a FID analyser that meets the specifications of Clause 7.3. The FID response shall be used as the reference hydrocarbon value.

c) Upstream of any sample dryer, if one is used during testing, the engine exhaust shall be introduced into the NDUV analyser.

d) Time shall be allowed for the analyser response to stabilize. Stabilization time may include time to purge the transfer tube and to account for analyser response.

e) While all analysers measure the sample's concentration, 30 s of sampled data shall be recorded, and the arithmetic means for the three analysers calculated;

f) The CLD mean shall be subtracted from the NDUV mean.

g) This difference shall be multiplied by the ratio of the expected mean HC concentration to the HC concentration measured during the verification. The analyser meets the interference verification of this subclause if this result is within ±2 % of the NO_x concentration expected at the standard:

$$\left|\bar{x}_{\mathrm{NOx,CLD,meas}} - \bar{x}_{\mathrm{NOx,NDUV,meas}}\right| * \left(\frac{\bar{x}_{\mathrm{HC,exp}}}{\bar{x}_{\mathrm{HC,meas}}}\right) \leq 2\,\% * \left(\bar{x}_{\mathrm{NOx,exp}}\right) \qquad (9)$$

where

$x_{\mathrm{NO,CLD,meas}}$	is the flow-weighted mean concentration of NO_x measured by CLD [µmol/mol];
$x_{\mathrm{NO,NDUV,meas}}$	is the flow-weighted mean concentration of NO_x measured by NDUV [µmol/mol];
$x_{\mathrm{HC,meas}}$	is the flow-weighted mean concentration of HC measured [µmol/mol];
$x_{\mathrm{HC,exo}}$	is the flow-weighted mean concentration of HC expected at the standard [µmol/mol];
$x_{\mathrm{NO,exp}}$	is the flow-weighted mean concentration of NO_x expected at the standard [µmol/mol].

9.5.9.2.5 Cooling bath (chiller) requirements

It shall be demonstrated that for the highest expected water vapour concentration H_m, the water removal technique maintains CLD humidity at ≤5 g water/kg dry air (or about 0,8 volume % H_2O), which is 100 % relative humidity at 3,9 °C and 101,3 kPa. This humidity specification is also equivalent to about 25 % relative humidity at 25 °C and 101,3 kPa. This may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD.

9.5.9.3 Cooling bath (chiller) NO_2 penetration

9.5.9.3.1 Scope and frequency

If a cooling bath (chiller) is used to dry a sample upstream of a NO_x measurement instrument, but no NO_2-to-NO converter is used upstream of the cooling bath, this verification shall be performed for cooling bath NO_2 penetration. This verification shall be performed after initial installation and after major maintenance.

9.5.9.3.2 Measurement principles

A cooling bath (chiller) removes water, which can otherwise interfere with a NO_x measurement. However, liquid water remaining in an improperly designed cooling bath can remove NO_2 from the sample. If a cooling bath is used without an NO_2-to-NO converter upstream, it could therefore remove NO_2 from the sample prior NO_x measurement.

9.5.9.3.3 System requirements

The chiller shall allow for measuring at least 95 % of the total NO_2 at the maximum expected concentration of NO_2.

9.5.9.3.4 Procedure

The following procedure shall be used to verify chiller performance:

a) Instrument setup. The analyser and chiller manufacturers' start-up and operating instructions shall be followed. The analyser and chiller shall be adjusted as needed to optimize performance.

b) Equipment setup and data collection.

   1) The total NO_x gas analyser(s) shall be zeroed and spanned as it would be before emission testing.

   2) NO_2 calibration gas (balance gas of dry air) that has an NO_2 concentration that is near the maximum expected during testing shall be selected. Higher concentration may be used according to the instrument manufacturer's recommendation and good engineering judgement in order to obtain accurate verification, if the expected NO_2 concentration is lower than the minimum range for the verification specified by the instrument manufacturer.

   3) This calibration gas shall be overflowed at the gas sampling system's probe or overflow fitting. Time shall be allowed for stabilization of the total NO_x response, accounting only for transport delays and instrument response.

   4) The mean of 30 s of recorded total NO_x data shall be calculated and this value recorded as x_{NOxref}.

   5) The flowing of the NO_2 calibration gas shall be stopped.

   6) Next the sampling system shall be saturated by overflowing a dew point generator's output, set at a dew point of 50 °C, to the gas sampling system's probe or overflow fitting. The dew point generator's output shall be sampled through the sampling system and chiller for at least 10 min until the chiller is expected to be removing a constant rate of water.

   7) It shall be immediately switched back to overflowing the NO_2 calibration gas used to establish x_{NOxref}. It shall be allowed for stabilization of the total NO_x response, accounting only for transport delays and instrument response. The mean of 30 s of recorded total NO_x data shall be calculated and this value recorded as x_{NOxmeas}.

8) x_{NOxmeas} shall be corrected to x_{NOxdry} based upon the residual water vapour that passed through the chiller at the chiller's outlet temperature and pressure.

c) Performance evaluation. If x_{NOxdry} is less than 95 % of x_{NOxref}, the chiller shall be repaired or replaced.

9.5.9.4 Interference verification for SO_2 NDIR or FTIR analysers

9.5.9.4.1 Scope and frequency

If SO_2 is measured using NDIR or FTIR analyser, the amount of interference shall be verified after initial analyser installation and after major maintenance

9.5.9.4.2 Measurement principles

Interference gases can positively interfere with certain analysers by causing a response similar to SO_2. If the analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyser interference verification.

When running the interference verification for these analysers, use interference gases as follows:

a) The interference gases for NDIR analysers are CO, CO_2, NO, C_3H_8 and H_2O Note that interference species, with the exception of H_2O, are dependent on the SO_2 infrared absorption band chosen by the instrument manufacturer. For each analyser determine the SO_2 infrared absorption band. For each SO_2 infrared absorption band, good engineering judgment shall be used to determine which interference gases to use in the verification.

b) Good engineering judgment shall be used to determine interference gases for FTIR analysers. Note that interference species, with the exception of H_2O, are dependent on the SO_2 infrared absorption band chosen by the instrument manufacturer. For each analyser determine the SO_2 infrared absorption band. For each SO_2 infrared absorption band, good engineering judgment shall be used to determine interference gases to use in the verification.

9.5.9.4.3 System requirements

SO_2 analysers shall have combined interference that is within ±2 % of the flow-weighted mean concentration of SO_2 expected during testing or expected at standard, if applicable.

9.5.9.4.4 Procedure

The interference verification shall be performed as follows:

a) The SO_2 analyser shall be started, operated, zeroed, and spanned as it would be before an emission test.

b) A humidified interference test gas shall be created by bubbling a multi component span gas through distilled H_2O in a sealed vessel. If the sample is not passed through a dryer the vessel temperature shall be controlled to generate an H_2O level at least as high as the maximum expected during emission testing. If the sample is passed through a dryer during emission testing, the vessel temperature shall be controlled to generate an H_2O level at least as high as the level determined in 5.2.2.3.1. Interference span gas concentrations shall be used at least as high as the maximum expected during testing.

c) The humidified interference test gas shall be introduced into the sample system. The humidified interference test gas may be introduced downstream of any sample dryer, if one is used during testing.

d) The water mole fraction, x_{H2O}, of the humidified interference test gas shall be measured, as close as possible to the inlet of the analyser. For example, dew point, T_{dew}, and absolute pressure, p_{total}, shall be measured to calculate x_{H2O}.

e) Good engineering judgment shall be used to prevent condensation in the transfer tubes, fittings, or valves from the point where x_{H2O} is measured to the analyser.

f) Time shall be allowed for the analyser response to stabilize.

g) While the analyser measures the sample's concentration, its output shall be recorded for 30 s. The arithmetic mean of this data shall be calculated.

h) The analyser meets the interference verification if the result of g) meets the tolerance in 9.5.9.4.3.

i) Interference procedures for individual interference gases may also run separately. If the interference gas levels used are higher than the maximum levels expected during testing, each observed interference value may be scaled down by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. Separate interference concentrations of H_2O (down to 0,025 mol/mol H_2O content) that are lower than the maximum levels expected during testing may be run, but the observed H_2O interference shall be scaled up by multiplying the observed interference by the ratio of the maximum expected H_2O concentration value to the actual value used during this procedure. The sum of the scaled interference values shall meet the tolerance for combined interference as specified in 9.5.9.4.3.

9.5.9.5 Cross-interference check compensation for NH_3 channels using IR and UV measurement techniques

For FTIR and NDUV measurement systems, the cross-interference check shall be conducted according to the instrument manufacturer's instructions.

9.5.9.5.1 Procedure for establishing the cross-interference correction for NH_3 analysers (NDUVR method)

There are cross-interferences to nitrogen oxide (NO) and nitrogen dioxide (NO_2). Both components shall be measured with the measurement equipment and a compensation shall be applied to the analyser readings, if the cross-interference exceeds 2 % full scale.

9.5.9.5.2 Check of the cross-interferences

NO and NO_2 calibration gases are fed into the analyser with cross-interference compensation activated. For each component, at least five different calibration gas concentrations with equidistant spacing between zero and the maximum expected interference gas concentration shall be used for the compensation check. The maximum deviation of the NH_3 reading from the zero reading shall be less than ±2 % full scale of the commonly used range. If the deviation is higher, a new correction curve for the corresponding interference component shall be established and applied to the analyser readings. The use of single-blend gases is possible, as well as the use of gas mixtures containing two or more interference gases.

9.5.9.5.3 Procedure for the generation of cross-interference correction curves

9.5.9.5.3.1 NO cross-interference

Calibration gases with at least five different NO concentrations that have to be spread equidistantly over the used NO analyser range during measurement shall be fed into the NH_3 analyser.

The nominal NO values and the measured NH_3 concentrations have to be recorded. Using a least-squares fit for a suitable fit function (e.g. polynomial fit function) $f(C_{NO})$, a correction curve to compensate for the NO cross-interference is calculated. The number of fit points has to be higher by at least two than the number of fit parameters (e.g. polynomial of fourth order needs at least seven fit points). The correction values $C_{\mathrm{NH3\_compensated}} = C_{\mathrm{NH3\_not\ compensated}} - f(C_{\mathrm{NO}})$ should be within ±1 % full scale of the analyser zero reading.

9.5.9.5.3.2 NO_2 cross-interference

The procedure for NO_2 is equivalent to that for NO_2 span gases. The result is the correction curve $f(C_{\mathrm{NO2}})$.

The calibration gases used for establishing the cross-interference compensation curves shall be single-blend mixtures. The use of gas mixtures with two or more interference gases is not allowed for generating the cross-interference compensation curves.

The following compensation calculation should be done by the measurement system:

$$C_{NH3\_\mathrm{compensated}} = C_{NH3\_\mathrm{not\ compensated}} - f(C_{\mathrm{NO}}) - f(C_{\mathrm{NO2}}) \quad (10)$$

After the compensation curves have been established, the cross-interference compensation shall be checked by the procedures given in 9.5.9.5.1.

9.5.9.6 Interference verification for N_2O analysers

9.5.9.6.1 Scope and frequency

If N_2O is measured using NDIR, FTIR or laser infrared analyser, the amount of interference shall be verified after initial analyser installation and after major maintenance.

9.5.9.6.2 Measurement principles

Interference gases can positively interfere with certain analysers by causing a response similar to N_2O. If the analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyser interference verification.

When running the interference verification for these analysers, use interference gases as follows:

a) The interference gases for NDIR analysers are CO, CO_2, H_2O, CH_4, and SO_2. Note that interference species, with the exception of H_2O, are dependent on the N_2O infrared absorption band chosen by the instrument manufacturer. For each analyser determine the N_2O infrared absorption band. For each N_2O infrared absorption band, good engineering judgment shall be used to determine which interference gases to use in the verification.

b) Good engineering judgment shall be used to determine interference gases for FTIR, and laser infrared analysers. Note that interference species, with the exception of H_2O, are dependent on the N_2O infrared absorption band chosen by the instrument manufacturer. For each analyser determine the N_2O infrared absorption band. For each N_2O infrared absorption band, good engineering judgment shall be used to determine interference gases to use in the verification.

9.5.9.6.3 System requirements

Analysers shall have combined interference that is within 1,0 µmol/mol.

9.5.9.6.4 Procedure

The interference verification shall be performed as follows:

a) The N_2O analyser shall be started, operated, zeroed, and spanned as it would be before an emission test.

b) A humidified interference test gas shall be created by bubbling a multi component span gas through distilled H_2O in a sealed vessel. If the sample is not passed through a dryer the vessel temperature shall be controlled to generate an H_2O level at least as high as the maximum expected during emission testing. If the sample is passed through a dryer during emission testing, the vessel temperature shall be controlled to generate an H_2O level at least as high as the level determined in 5.2.2.3.1. Interference span gas concentrations shall be used at least as high as the maximum expected during testing.

c) The humidified interference test gas shall be introduced into the sample system. The humidified interference test gas may be introduced downstream of any sample dryer, if one is used during testing.

d) The water mole fraction, x_{H2O}, of the humidified interference test gas shall be measured, as close as possible to the inlet of the analyser. For example, dew point, T_{dew}, and absolute pressure, p_{total}, shall be measured to calculate x_{H2O}.

e) Good engineering judgment shall be used to prevent condensation in the transfer tubes, fittings, or valves from the point where x_{H2O} is measured to the analyser.

f) Time shall be allowed for the analyser response to stabilize.

g) While the analyser measures the sample's concentration, its output shall be recorded for 30 s. The arithmetic mean of this data shall be calculated.

h) The analyser meets the interference verification if the result of g) meets the tolerance in 9.5.9.6.3.

i) Interference procedures for individual interference gases may also run separately. If the interference gas levels used are higher than the maximum levels expected during testing, each observed interference value may be scaled down by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. Separate interference concentrations of H_2O (down to 0,025 mol/mol H_2O content) that are lower than the maximum levels expected during testing may be run, but the observed H_2O interference shall be scaled up by multiplying the observed interference by the ratio of the maximum expected H_2O concentration value to the actual value used during this procedure. The sum of the scaled interference values shall meet the tolerance for combined interference as specified in 9.5.9.6.3.

9.5.9.7 Interference verification for NO_x laser infrared analysers

9.5.9.7.1 Scope and frequency

If the NO_x is determined by summing NO and NO_2 concentrations measured using laser infrared analyser, the amount of interference shall be verified after initial analyser installation and after major maintenance.

9.5.9.7.2 Measurement principles

Interference gases can positively interfere with certain laser infrared analyser by causing a response similar to NO and NO_2. If the analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyser interference verification.

Good engineering judgment shall be used to determine interference gases for laser infrared analyser. Note that interference species, with the exception of H_2O, are dependent on the NO and NO_2 infrared absorption band chosen by the instrument manufacturer. For each analyser determine the NO and NO_2 infrared absorption band. For each NO and NO_2 infrared absorption band, good engineering judgment shall be used to determine interference gases to use in the verification.

9.5.9.7.3 System requirements

A NO and NO_2 analyser shall have combined interference within ±2 % of the flow-weighted mean concentration of NO_x that would correspond to the applicable limit value.

9.5.9.7.4 Procedure

The interference verification shall be performed as follows:

a) The NO and NO_2 analyser shall be started, operated, zeroed, and spanned as it would be before an emission test.

b) A humidified interference test gas shall be created by bubbling a multi component span gas through distilled H_2O in a sealed vessel. If the sample is not passed through a dryer the vessel temperature shall be controlled to generate an H_2O level at least as high as the maximum expected during emission testing. If the sample is passed through a dryer during emission testing, the vessel temperature shall be controlled to generate an H_2O level at least as high as the level determined in 5.2.2.3.1. Interference span gas concentrations shall be used at least as high as the maximum expected during testing.

c) The humidified interference test gas shall be introduced into the sample system. The humidified interference test gas may be introduced downstream of any sample dryer, if one is used during testing.

d) The water mole fraction, x_{H2O}, of the humidified interference test gas shall be measured, as close as possible to the inlet of the analyser. For example, dew point, T_{dew}, and absolute pressure, p_{total}, shall be measured to calculate x_{H2O}.

e) Good engineering judgment shall be used to prevent condensation in the transfer tubes, fittings, or valves from the point where x_{H2O} is measured to the analyser.

f) Time shall be allowed for the analyser response to stabilize.

g) While the analyser measures the sample's concentration, its output shall be recorded for 30 s. The arithmetic mean of this data shall be calculated.

h) The analyser meets the interference verification if the result of g) meets the tolerance in 9.5.9.7.3.

i) Interference procedures for individual interference gases may also run separately. If the interference gas levels used are higher than the maximum levels expected during testing, each observed interference value may be scaled down by multiplying the observed interference by the ratio of the maximum expected concentration value to the actual value used during this procedure. Separate interference concentrations of H_2O (down to 0,025 mol/mol H_2O content) that are lower than the maximum levels expected during testing may be run, but the observed H_2O interference shall be scaled up by multiplying the observed interference by the ratio of the maximum expected H_2O concentration value to the actual value used during this procedure. The sum of the scaled interference values shall meet the tolerance for combined interference as specified in 9.5.9.7.3.

9.5.10 Methanol response factor

When the FID analyser is to be used for the analysis of hydrocarbons containing methanol, the methanol response factor (r_m) of the analyser shall be established.

A known volume of methanol (*a*, in millilitres) is injected, using a microlitre syringe, into the heated mixing zone [122 °C] of a septum injector, vapourized and swept into a tedlar bag with a known volume of zero-grade air (*b*, in cubic metres). The air volume(s) shall be such that the methanol concentration in the bag is representative of the range of concentrations found in the exhaust sample.

The bag sample is analysed using the FID, and the response factor is calculated as follows:

$$r_m = \frac{x_{FID}}{c_{SAM}} \quad (11)$$

where

x_{FID} is the FID reading, in parts per million (microlitres per litre) of C;

c_{SAM} is the methanol concentration in the sample bag in µmol/molC, as calculated from a and b: $c_{SAM} = 594 \times a/b$.

In case the calculation is not performed a response factor r_m of 0,63 shall be used.

9.6 Calibration of the particulate mass measuring system

9.6.1 General

Each component shall be calibrated as often as necessary to fulfil the accuracy requirements of this document. The calibration method to be used is described in this subclause for the components indicated in Clause 8.

9.6.2 Checking the partial flow conditions

The range of the exhaust gas velocity and the pressure oscillations shall be checked and adjusted according to the requirements of 8.3.2, exhaust pipe explanations are also shown in Figures E.1 to E.8, if applicable.

9.6.3 PM balance verifications and weighing process verification

9.6.3.1 Scope and frequency

This subclause describes three verifications.

a) independent verification of PM balance performance within 370 days prior to weighing any filter;

b) zero and span of the balance within 12 h prior to weighing any filter;

c) verification that the mass determination of reference filters before and after a filter weighing session be less than a specified tolerance.

9.6.3.2 Independent verification

The balance manufacturer (or a representative approved by the balance manufacturer) shall verify the balance performance within 370 days of testing in accordance with internal audit procedures.

9.6.3.3 Zeroing and spanning

Balance performance shall be verified by zeroing and spanning it with at least one calibration weight, and any weights that are used shall meet the specifications in 8.1.5.2 to perform this verification. A manual or automated procedure shall be used:

a) A manual procedure requires that the balance shall be used in which the balance shall be zeroed and spanned with at least one calibration weight. If normally mean values are obtained by repeating the weighing process to improve the accuracy and precision of PM measurements, the same process shall be used to verify balance performance.

b) An automated procedure is carried out with internal calibration weights that are used automatically to verify balance performance. These internal calibration weights shall meet the specifications in 8.1.5.2 to perform this verification.

9.6.3.4 Reference sample weighing

All mass readings during a weighing session shall be verified by weighing reference PM sample media (e.g. filters) before and after a weighing session. A weighing session may be as short as desired, but no longer than 80 hours, and may include both pre- and post-test mass readings. Successive mass determinations of each reference PM sample media shall return the same value within ±10 µg or ±10 % of the expected total PM mass, whichever is higher. Should successive PM sample filter weighing events fail this criterion, all individual test filter mass readings mass readings occurring between the successive reference filter mass determinations shall be invalidated. These filters may be re-weighed in another weighing session. Should a post-test filter be invalidated then the test interval is void. This verification shall be performed as follows:

a) At least two samples of unused PM sample media shall be kept in the PM-stabilization environment. These shall be used as references. Unused filters of the same material and size shall be selected for use as references.

b) References shall be stabilized in the PM stabilization environment. References shall be considered stabilized if they have been in the PM-stabilization environment for a minimum of 30 min, and the PM-stabilization environment has been within the specifications of 8.1.5.1 for at least the preceding 60 min.

c) The balance shall be exercised several times with a reference sample without recording the values.

d) The balance shall be zeroed and spanned. A test mass shall be placed on the balance (e.g. calibration weight) and then removed ensuring that the balance returns to an acceptable zero reading within the normal stabilization time.

e) Each of the reference media (e.g. filters) shall be weighed and their masses recorded. If normally mean values are obtained by repeating the weighing process to improve the accuracy and precision of reference media (e.g. filters) masses, the same process shall be used to measure mean values of sample media (e.g. filters) masses.

f) The balance environment dew point, ambient temperature, and atmospheric pressure shall be recorded.

g) The recorded ambient conditions shall be used to correct results for buoyancy as described in 9.6.3.5. The buoyancy-corrected mass of each of the references shall be recorded.

h) Each of the reference media's (e.g. filter's) buoyancy-corrected reference mass shall be subtracted from its previously measured and recorded buoyancy-corrected mass.

i) If any of the reference filters' observed mass changes by more than that allowed under this subclause, all PM mass determinations made since the last successful reference media (e.g. filter) mass validation shall be invalidated. Reference PM filters maybe discarded if only one of the filters mass has changed by more than the allowable amount and a special cause for that filter's mass change can be positively identified which would not have affected other in-process filters. Thus the validation can be considered a success. In this case, the contaminated reference media shall not be included when determining compliance with j) of this subclause, but the affected reference filter shall be discarded and replaced.

j) If any of the reference masses change by more than that allowed under 9.6.3.4, all PM results that were determined between the two times that the reference masses were determined shall be invalidated. If reference PM sample media is discarded according to i) of this subclause, at least one reference mass difference that meets the criteria in 9.6.3.4 shall be available. Otherwise, all PM results that were determined between the two times that the reference media (e.g. filters) masses were determined shall be invalidated.

9.6.3.5 PM sample filter buoyancy correction

9.6.3.5.1 General

PM sample filter shall be corrected for their buoyancy in air. The buoyancy correction depends on the sample media density, the density of air, and the density of the calibration weight used to calibrate the balance. The buoyancy correction does not account for the buoyancy of the PM itself, because the mass of PM typically accounts for only (0,01 to 0,10) % of the total weight. A correction to this small fraction of mass would be at the most 0,010 %. The buoyancy-corrected values are the tare masses of the PM samples. These buoyancy-corrected values of the pre-test filter weighing are subsequently subtracted from the buoyancy-corrected values of the post-test weighing of the corresponding filter to determine the mass of PM emitted during the test.

9.6.3.5.2 PM sample filter density

Different PM sample filter have different densities. The known density of the sample media shall be used, or one of the densities for some common sampling media shall be used, as follows:

a) For PTFE-coated borosilicate glass, a sample media density of 2 300 kg/m^3 shall be used.

b) For PTFE membrane (film) media with an integral support ring of polymethylpentene that accounts for 95 % of the media mass, a sample media density of 920 kg/m^3 shall be used.

c) For PTFE membrane (film) media with an integral support ring of PTFE, a sample media density of 2 144 kg/m^3 shall be used.

9.6.3.5.3 Air density

Because a PM balance environment shall be tightly controlled to an ambient temperature of (22 ± 1) °C and a dew point of (9,5 ± 1) °C, air density is primarily function of atmospheric pressure. Therefore a buoyancy correction is specified that is only a function of atmospheric pressure.

9.6.3.5.4 Calibration weight density

The stated density of the material of the metal calibration weight shall be used.

9.6.3.5.5 Correction calculation

The PM sample filter shall be corrected for buoyancy using the following formulae:

$$m_{\text{cor}} = m_{\text{uncor}} \left(\frac{1 - \dfrac{\rho_{\text{air}}}{\rho_{\text{weight}}}}{1 - \dfrac{\rho_{\text{air}}}{\rho_{\text{media}}}} \right) \qquad (12)$$

where

m_{cor}	is PM sample filter mass corrected for buoyancy;
m_{uncor}	is PM sample filter mass uncorrected for buoyancy;
ρ_{air}	is density of air in balance environment;
ρ_{weight}	is density of calibration weight used to span balance;
ρ_{media}	is density of PM sample filter.

$$\rho_{\mathrm{air}} = \frac{p_{\mathrm{a}} * M_{\mathrm{mix}}}{R * T_{\mathrm{a}}} \tag{13}$$

where

p_{a}	is absolute pressure in balance environment;
M_{mix}	is molar mass of air in balance environment;
R	is molar gas constant;
T_{a}	is absolute ambient temperature of balance environment.

9.7 Calibration of the particle number measuring system

9.7.1 Calibration of the particle number counter

Based on the agreement between the parties involved, the existence of a calibration certificate for the PNC shall be ensured, demonstrating compliance with a traceable standard within a 12-month period prior to the emissions test.

The PNC shall also be recalibrated and a new calibration certificate issued following any major maintenance.

Calibration shall be traceable to a standard calibration method:

a) by comparison of the response of the PNC under calibration with that of a calibrated aerosol electrometer when simultaneously sampling electrostatically classified calibration particles; or

b) by comparison of the response of the PNC under calibration with that of a second PNC which has been directly calibrated by the above method.

In the electrometer case, calibration shall be undertaken using at least six standard concentrations spaced as uniformly as possible across the PNC's measurement range. These points will include a nominal zero concentration point produced by attaching HEPA filters of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of each instrument. With no calibration factor applied to the PNC under calibration, measured concentrations shall be within ±10 % of the standard concentration for each concentration used, with the exception of the zero point, otherwise the PNC under calibration shall be rejected. The gradient from a linear regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the PNC under calibration. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (R^2) of the two data sets and shall be equal to or greater than 0,97. In calculating both the gradient and R^2 the linear regression shall be forced through the origin (zero concentration on both instruments).

In the reference PNC case, calibration shall be undertaken using at least six standard concentrations across the PNC's measurement range. At least 3 points shall be at concentrations below 1 000 cm^{-3}, the remaining concentrations shall be linearly spaced between 1 000 cm^{-3} and the maximum of the PNC's range in single particle count mode. These points will include a nominal zero concentration point produced by attaching HEPA filters of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of each instrument. With no calibration factor applied to the PNC under calibration, measured concentrations shall be within ±10 % of the standard concentration for each concentration, with the exception of the zero point, otherwise the PNC under calibration shall be rejected. The gradient from a linear regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the PNC under calibration. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (R^2) of the two data sets and shall be equal to or greater than 0,97. In calculating both the gradient and R^2 the linear regression shall be forced through the origin (zero concentration on both instruments).

Calibration shall also include a check, against the requirements in 8.4.3.2, on the PNC's detection efficiency with particles of 23 nm electrical mobility diameter. A check of the counting efficiency with 41 nm particles is not required.

9.7.2 Calibration/Validation of the volatile particle remover

Calibration of the VPR's particle concentration reduction factors across its full range of dilution settings, at the instrument's fixed nominal operating temperatures, shall be required when the unit is new and following any major maintenance. The periodic validation requirement for the VPR's particle concentration reduction factor is limited to a check at a single setting, typical of that used for measurement on diesel particulate filter equipped vehicles. Based on the agreement between the parties involved, the existence of a calibration or validation certificate for the volatile particle remover shall be ensured within a 6-month period prior to the emissions test. If the volatile particle remover incorporates temperature monitoring alarms a 12-month validation interval shall be permissible.

The VPR shall be characterised for particle concentration reduction factor with solid particles of 30 nm, 50 nm and 100 nm electrical mobility diameter. Particle concentration reduction factors ($f_r(d)$) for particles of 30 nm and 50 nm electrical mobility diameters shall be no more than 30 % and 20 % higher respectively, and no more than 5 % lower than that for particles of 100 nm electrical mobility diameter. For the purposes of validation, the mean particle concentration reduction factor shall be within ±10 % of the mean particle concentration reduction factor ($\bar{f}_r$) determined during the primary calibration of the VPR.

The test aerosol for these measurements shall be solid particles of 30, 50 and 100 nm electrical mobility diameter and a minimum concentration of 5 000 particles cm^{-3} at the VPR inlet. Particle concentrations shall be measured upstream and downstream of the components.

The particle concentration reduction factor at each particle size ($f_r(d_i)$) shall be calculated as follows:

$$f_r(d_i)=\frac{N_{in}(d_i)}{N_{out}(d_i)} \tag{14}$$

where

$N_{in}(d_i)$ is upstream particle number concentration for particles of diameter *di*;

$N_{out}(d_i)$ is downstream particle number concentration for particles of diameter d_i;

d_i is particle electrical mobility diameter (30, 50 or 100 nm).

$N_{in}(d_i)$ and $N_{out}(d_i)$ shall be corrected to the same conditions.

The mean particle concentration reduction ($\bar{f}_r$) at a given dilution setting shall be calculated as follows:

$$\bar{f}_r=\frac{f_r(30\text{nm})+f_r(50\text{nm})+f_r(100\text{nm})}{3} \tag{15}$$

The VPR should be calibrated and validated as a complete unit.

Based on the agreement between the parties involved, the existence of a validation certificate for the VPR shall be ensured, demonstrating effective volatile particle removal efficiency within a 6-month period prior to the emissions test. If the volatile particle remover incorporates temperature monitoring alarms a 12-month validation interval shall be permissible. The VPR shall demonstrate greater than 99,0 % removal of tetracontane ($CH_3(CH_2)_{38}CH_3$) particles of at least 30 nm electrical mobility diameter with an inlet concentration of ≥10 000 particles/cm^3 when operated at its minimum dilution setting and manufacturers recommended operating temperature.

9.7.3 Particle number system check procedures

Prior to each test, the particle counter shall report a measured concentration of less than 0,5 particles cm^{-3} when a HEPA filter of at least class H13 of EN 1822:2008, or equivalent performance, is attached to the inlet of the entire particle sampling system (VPR and PNC).

On a monthly basis, the flow into the particle counter shall report a measured value within 5 % of the particle counter nominal flow rate when checked with a calibrated flow meter.

Each day, following the application of a HEPA filter of at least class H13 of EN 1822:2008, or equivalent performance, to the inlet of the particle counter, the particle counter shall report a concentration of $\leq 0,2$ cm^{-3}. Upon removal of this filter, the particle counter shall show an increase in measured concentration to at least 100 particles cm^{-3} when challenged with ambient air and a return to $\leq 0,2$ cm^{-3} on replacement of the HEPA filter.

Prior to the start of each test it shall be confirmed that the measurement system indicates that the evaporation tube, where featured in the system, has reached its correct operating temperature.

Prior to the start of each test it shall be confirmed that the measurement system indicates that the diluter PND 1 has reached its correct operating temperature.

9.8 Calibration of the CVS full flow dilution system

9.8.1 General

a) This subclause describes how to calibrate flow meters for diluted exhaust constant-volume sampling (CVS) systems.

b) This calibration shall be performed while the flow meter is installed in its permanent position. This calibration shall be performed after any part of the flow configuration upstream or downstream of the flow meter has been changed that may affect the flow-meter calibration. This calibration shall be performed upon initial CVS installation and whenever corrective action does not resolve a failure to meet the diluted exhaust flow verification (i.e., propane check) in 9.8.5.

c) A CVS flow meter shall be calibrated using a reference flow meter such as a subsonic venturi flow meter, a long-radius flow nozzle, a smooth approach orifice, a laminar flow element, a set of critical flow venturis, or an ultrasonic flow meter. A reference flow meter shall be used that reports quantities that are internationally-traceable within ±1 % uncertainty. This reference flow meter's response to flow shall be used as the reference value for CVS flow-meter calibration.

d) An upstream screen or other restriction that could affect the flow ahead of the reference flow meter may not be used, unless the flow meter has been calibrated with such a restriction.

e) The calibration sequence described under this 9.8 refers to the molar based approach. For the corresponding sequence used in the mass based approach, see 9.8.2.

f) By the choice of the manufacturer, CFV or SSV may alternatively be removed from its permanent position for calibration as long as the following requirements are met when installed in the CVS:

   1) Upon installation of the CFV or SSV into the CVS, good engineering judgment shall be applied to verify that you have not introduced any leaks between the CVS inlet and the venturi.

   2) After ex-situ venturi calibration, all venturi flow combinations shall be verified for CFVs or at minimum of 10 flow points for an SSV using the propane check as described in 9.8.5. The result of the propane check for each venturi flow point may not exceed the tolerance in 9.8.5.6.

3) In order to verify the ex-situ calibration for a CVS with more than a single CFV, the following check to verify that there are no flow meter entrance effects that can prevent you from passing this verification, shall be performed as follows:

   i) A constant flow device like a CFO kit shall be used to deliver a constant flow of propane to the dilution tunnel.

   ii) The hydrocarbon concentrations shall be measured at a minimum of 10 separate flow rates for an SSV flow meter, or at all possible flow combinations for a CFV flow meter, while keeping the flow of propane constant.

   iii) The concentration of hydrocarbon background in the dilution air shall be measured at the beginning and end of this test. The average background concentration from each measurement at each flow point shall be subtracted before performing the regression analysis in iv).

   iv) A power regression has to be performed using all the paired values of flow rate and corrected concentration to obtain a relationship in the form of $y = a^*x^b$, using the concentration as the independent variable and the flow rate as the dependent variable. For each data point, the calculation of the difference between the measured flow rate and the value represented by the curve fit is required. The difference at each point shall be less than ±1 % of the appropriate regression value. The value of b shall be between −1,005 and −0,995. If the results do not meet these limits, corrective actions consistent with 9.8.5.1 shall be taken.

9.8.2 Calibration of the Positive Displacement Pump (PDP)

9.8.2.1 General

A positive-displacement pump (PDP) shall be calibrated to determine a flow-versus- PDP speed equation that accounts for flow leakage across sealing surfaces in the PDP as a function of PDP inlet pressure. Unique equation coefficients shall be determined for each speed at which the PDP is operated. A PDP flow meter shall be calibrated as follows:

a) The system shall be connected as shown in Figure 15.

b) Leaks between the calibration flow meter and the PDP shall be less than 0,3 % of the total flow at the lowest calibrated flow point; for example, at the highest restriction and lowest PDP-speed point.

c) While the PDP operates, a constant temperature at the PDP inlet shall be maintained within ±2 % of the mean absolute inlet temperature, T_{in}.

d) The PDP speed is set to the first speed point at which it is intended to calibrate.

e) The variable restrictor is set to its wide-open position.

f) The PDP is operated for at least 3 min to stabilize the system. Then by continuously operating the PDP, the mean values of at least 30 s of sampled data of each of the following quantities are recorded:

   1) the mean flow rate of the reference flow meter $\bar{q}_{V\text{ref}}$; this may include several measurements of different quantities, such as reference meter pressures and temperatures, for calculating $\bar{q}_{V\text{ref}}$;

   2) the mean temperature at the PDP inlet, T_{in};

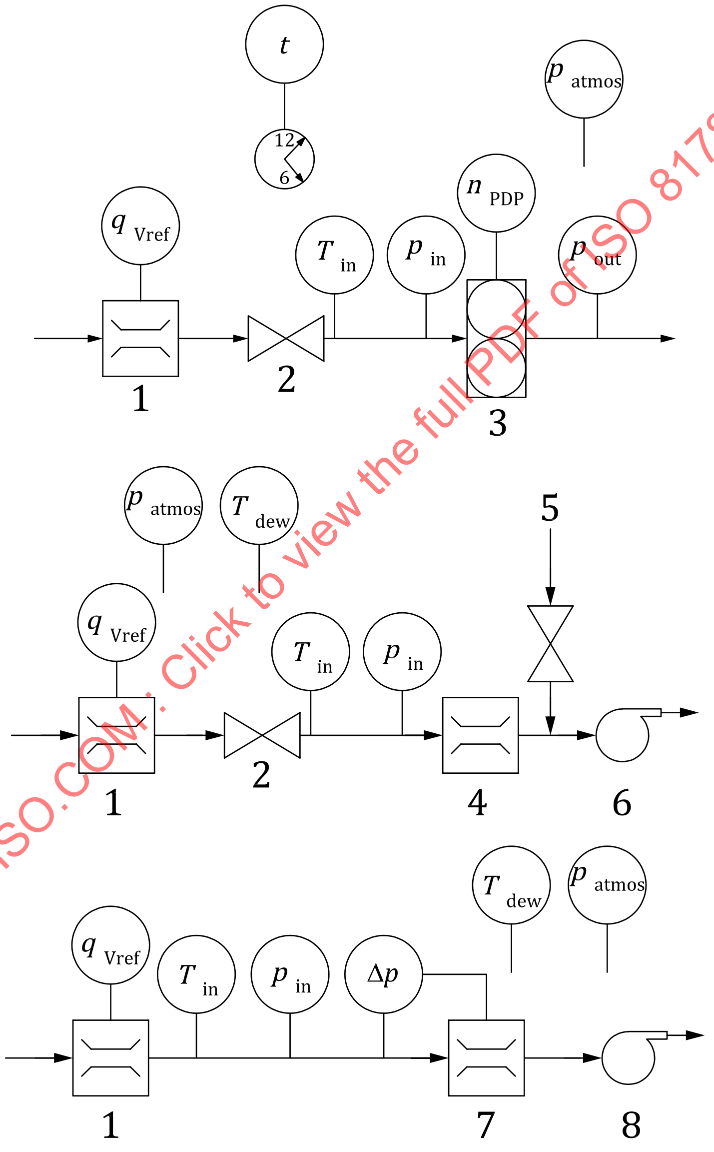
   3) the mean static absolute pressure at the PDP inlet, p_{in};

   4) the mean static absolute pressure at the PDP outlet, p_{out};

5) the mean PDP speed, n_{PDP};

g) The restrictor valve shall be incrementally closed to decrease the absolute pressure at the inlet to the PDP, p_{in}.

All the parameters related to the pump shall be simultaneously measured, along with the parameters related to a calibration venturi which is connected in series with the pump. The calculated flow rate (in m^3/min at pump inlet, absolute pressure and temperature) shall be plotted against a correlation function which is the value of a specific combination of pump parameters. The linear equation which relates the pump flow and the correlation function shall be determined. If a CVS has a multiple-speed drive, the calibration shall be performed for each range used.



Key

1	reference flow meter	5	downstream pressure control
2	variable restrictor	6	blower
3	PDP	7	SSV
4	CFV	8	variable speed blower

Figure 15 — Schematic diagrams for diluted exhaust flow CVS calibration

9.8.2.2 Data analysis

The air flow rate (q_{VCSV}) at each restriction setting (minimum six settings) shall be calculated in standard m^3/min from the flowmeter data using the manufacturer's prescribed method. The air flow rate shall then be converted to pump flow (V_0) in m^3/rev at absolute pump inlet temperature and pressure as follows:

$$V_0 = \frac{q_{VCSV}}{n} \times \frac{T}{273{,}15} \times \frac{101{,}325}{p_{\mathrm{a}}} \tag{16}$$

where

q_{VCSV} is the air flow rate at standard conditions (101,325 kPa, 273,15 K) [m^3/s];

T is the temperature at pump inlet [K];

p_{a} is the absolute pressure at pump inlet [kPa];

n is the pump speed [rev/s].

To account for the interaction of pressure variations at the pump and the pump slip rate, the correlation function (X_0) between pump speed, pressure differential from pump inlet to pump outlet, and absolute pump outlet pressure shall be calculated as follows:

$$X_0 = \frac{1}{n} \times \sqrt{\frac{\Delta p_{\mathrm{p}}}{p_{\mathrm{a}}}} \tag{17}$$

where

Δp_{p} is the pressure differential from pump inlet to pump outlet [kPa];

p_a is the absolute outlet pressure at pump outlet [kPa].

A linear least-squares fit shall be performed to generate the calibration Formula as follows:

$$V_0 = D_0 - m \times (X_0) \tag{18}$$

with D_0 [m^3/rev] and m [m^3/s], intercept and slope respectively, describing the regression line.

For a CVS system with multiple speeds, the calibration curves generated for the different pump flow ranges shall be approximately parallel, and the intercept values (D_0) shall increase as the pump flow range decreases.

The calculated values from the Formula shall be within ±0,5 % of the measured value of V_0. Values of m will vary from one pump to another. Particulate influx over time will cause the pump slip to decrease, as reflected by lower values for m. Therefore, calibration shall be performed at pump start-up, after major maintenance, and if the total system verification indicates a change of the slip rate.

9.8.3 Calibration of the Critical Flow Venturi (CFV)

9.8.3.1 General

A critical-flow venturi (CFV) shall be calibrated to verify its discharge coefficient, C_{d}, at the lowest expected static differential pressure between the CFV inlet and outlet. A CFV flow meter shall be calibrated as follows:

a) The system shall be connected as shown in Figure 15.

b) The blower shall be started downstream of the CFV.

c) While the CFV operates, a constant temperature at the CFV inlet shall be maintained within ±2 % of the mean absolute inlet temperature, T_{in}.

d) Leaks between the calibration flow meter and the CFV shall be less than 0,3 % of the total flow at the highest restriction.

e) The variable restrictor shall be set to its wide-open position. In lieu of a variable restrictor the pressure downstream of the CFV may be varied by varying blower speed or by introducing a controlled leak. Note that some blowers have limitations on non-loaded conditions.

f) The CFV shall be operated for at least 3 min to stabilize the system. The CFV shall continue operating and the mean values of at least 30 s of sampled data of each of the following quantities shall be recorded:

   1) the mean flow rate of the reference flow meter, $\bar{q}_{V\text{ref}}$; this may include several measurements of different quantities, such as reference meter pressures and temperatures, for calculating $\bar{q}_{V\text{ref}}$;

   2) optionally, the mean dew point of the calibration air, T_{dew}; see ISO 8178-4:2020, Annex H for permissible assumptions during emission measurements;

   3) the mean temperature at the venturi inlet, T_{in};

   4) the mean static absolute pressure at the venturi inlet, p_{in};

   5) the mean static differential pressure between the CFV inlet and the CFV outlet, Δp_{CFV};

g) The restrictor valve shall be incrementally closed to decrease the absolute pressure at the inlet to the CFV, p_{in}.

Calibration of the CFV is based upon the flow equation for a critical-flow venturi. Gas flow (Q_{s}) is a function of inlet pressure and temperature:

$$Q_{\text{s}} = \frac{k_{\text{V}} \times p_{\text{a}}}{\sqrt{T}} \tag{19}$$

where

k_{v} is the calibration coefficient;

p_{a} is the absolute pressure at the venturi inlet [kPa];

T is the temperature at the venturi inlet [K].

9.8.3.2 Data analysis

The air flow rate ($q_{V\text{CSV}}$) at each restriction setting (minimum eight settings) shall be calculated in standard m^3/min from the flowmeter data using the manufacturer's prescribed method. The calibration coefficient shall be calculated from the calibration data for each setting as follows:

$$k_{\text{V}} = \frac{q_{V\text{CSV}} \times \sqrt{T}}{p_{\text{a}}} \tag{20}$$

where

$q_{V\text{CSV}}$ is the air flow rate at standard conditions (101,325 kPa, 273,15 K) [m^3/s];

T is the temperature at the venturi inlet [K];

p_{a} is the absolute pressure at the venturi inlet [kPa].

To determine the range of critical flow, k_v shall be plotted as a function of venturi inlet pressure. For critical (choked) flow, k_v will have a relatively constant value. As pressure decreases (vacuum increases), the venturi becomes unchoked and k_v decreases, which indicates that the CFV is operating outside the permissible range.

For a minimum of eight points in the region of critical flow, the average k_v and the standard deviation shall be calculated. The standard deviation shall not exceed ±0,3 % of the average k_v.

9.8.4 Calibration of the subsonic venturi (SSV)

9.8.4.1 General

A subsonic venturi (SSV) shall be calibrated to determine its calibration coefficient, C_d, for the expected range of inlet pressures. An SSV flow meter shall be calibrated as follows:

a) The system shall be connected as shown in Figure 15.

b) The blower shall be started downstream of the SSV.

c) Leaks between the calibration flow meter and the SSV shall be less than 0,3 % of the total flow at the highest restriction.

d) While the SSV operates, a constant temperature at the SSV inlet shall be maintained within ±2 % of the mean absolute inlet temperature, T_in.

e) The variable restrictor or variable-speed blower shall be set to a flow rate greater than the greatest flow rate expected during testing. Flow rates may not be extrapolated beyond calibrated values, so it should be made certain that a Reynolds number, *Re*, at the SSV throat at the greatest calibrated flow rate is greater than the maximum *Re* expected during testing.

f) The SSV shall be operated for at least 3 min to stabilize the system. The SSV shall continue operating and the mean of at least 30 s of sampled data of each of the following quantities shall be recorded:

    1) the mean flow rate of the reference flow meter, $\bar{q}_{V\mathrm{ref}}$; this may include several measurements of different quantities, such as reference meter pressures and temperatures, for calculating $\bar{q}_{V\mathrm{ref}}$;

    2) optionally, the mean dew point of the calibration air, T_dew; see ISO 8178-4:2020, Annex H for permissible assumptions;

    3) the mean temperature at the venturi inlet, T_in;

    4) the mean static absolute pressure at the venturi inlet, p_in;

    5) static differential pressure between the static pressure at the venturi inlet and the static pressure at the venturi throat, Δp_SSV;

g) The restrictor valve shall be incrementally closed or the blower speed decreased to decrease the flow rate.

Calibration of the SSV is based upon the flow equation for a subsonic venturi. Gas flow is a function of inlet pressure and temperature, pressure drop between the SSV inlet and throat, as shown below:

$$q_{V\mathrm{SSV}} = \frac{A_0}{60} d_\mathrm{v}^{\,2} C_\mathrm{d} p_\mathrm{p} \sqrt{\left[\frac{1}{T} \left(r_\mathrm{x}^{1{,}428\,6} - r_\mathrm{x}^{1{,}714\,3} \right) \left(\frac{1}{1 - r_\mathrm{y}^4 r_\mathrm{x}^{1{,}428\,6}} \right) \right]} \qquad (21)$$

where

A_0 is a collection of constants and unit conversions

$$=0{,}0056940 \text{ in SI units of } \left[\frac{\mathrm{m}^3}{\mathrm{min}}\right]\left[\frac{K^{\frac{1}{2}}}{\mathrm{kPa}}\right]\left[\frac{1}{\mathrm{mm}^2}\right];$$

d_v is the diameter of the SSV throat [m];

C_d is the discharge coefficient of the SSV;

p_p is the absolute pressure at venturi inlet [kPa];

T is the temperature at the venturi inlet [K];

r_x is the ratio of the SSV throat to inlet absolute, static pressure, $r_\mathrm{x} = 1 - (\Delta p/p_\mathrm{a})$;

r_y is the ratio of d to the inlet pipe inner diameter (d_in), $r_\mathrm{y} = d/d_\mathrm{in}$.

9.8.4.2 Data analysis

The air flow rate ($q_{V\mathrm{SSV}}$) at each restriction setting (minimum 16 settings) shall be calculated in standard m^3/min from the flowmeter data using the manufacturer's prescribed method. The discharge coefficient (C_d) shall be calculated from the calibration data for each setting as follows:

$$C_\mathrm{d} = \frac{q_{V\mathrm{SSV}}}{\frac{A_0}{60} {d_\mathrm{v}}^2 p_\mathrm{p} \sqrt{\left[\frac{1}{T}\left(r_\mathrm{x}^{1{,}428\,6} - r_\mathrm{x}^{1{,}714\,3}\right)\left(\frac{1}{1 - r_\mathrm{y}^4 r_\mathrm{x}^{1{,}428\,6}}\right)\right]}} \tag{22}$$

where

A_0 is a collection of constants and unit conversions

$$=0{,}0056940 \text{ in SI units of } \left[\frac{\mathrm{m}^3}{\mathrm{min}}\right]\left[\frac{K^{\frac{1}{2}}}{\mathrm{kPa}}\right]\left[\frac{1}{\mathrm{mm2}}\right];$$

$q_{V\mathrm{SSV}}$ is the air flow rate at standard conditions (101,3 kPa, 273 K) [m^3/min];

T is the temperature at the venturi inlet [K];

d_v is the diameter of the SSV throat [m];

r_x is the ratio of the SSV throat to inlet absolute, static pressure, $r_\mathrm{x} = 1 - (\Delta p/p_\mathrm{a})$;

r_y is the ratio of d to the inlet pipe inner diameter (d_{in}), $r_\mathrm{y} = d/d_{in}$.

To determine the range of subsonic flow, C_d shall be plotted as a function of Reynolds number (Re), at the SSV throat. The Re at the SSV throat is calculated with the following formula:

$$Re = A_1 \times 60 \times \frac{q_{V\mathrm{SSV}}}{d_\mathrm{v} \mu} \tag{23}$$

where

A_1 is a collection of constants and unit conversions

$= 27{,}43831$ in SI units of $\left[\frac{\text{kg}}{\text{m}^3}\right]\left[\frac{\text{min}}{\text{s}}\right]\left[\frac{\text{mm}}{\text{m}}\right]$;

q_{VSSV} is the air flow rate at standard conditions (101,325 kPa, 273,15 K) [m^3/min];

d_v is the diameter of the SSV throat [m];

μ is the absolute or dynamic viscosity of the gas, calculated with the following formula:

$$\mu = \frac{bT^{3/2}}{S+T} = \frac{bT^{1/2}}{1+\frac{S}{T}} [\text{kg/m-s}] \tag{24}$$

where

b is an empirical constant $= 1{,}458 \times 10^6 \frac{\text{kg}}{\text{msK}^{1/2}}$;

S is an empirical constant = 110,04 K.

Because q_{VSSV} is an input to the *Re* formula, the calculations shall be started with an initial guess for q_{VSSV} or C_d of the calibration venturi, and repeated until q_{VSSV} converges. The convergence method shall be accurate to 0,1 % of a point or better.

For a minimum of sixteen points in the region of subsonic flow, the calculated values of C_d from the resulting calibration curve fit equation shall be within ±0,5 % of the measured C_d for each calibration point.

9.8.5 CVS and batch sampler verification (Propane check)

9.8.5.1 General

a) A propane check serves as a CVS verification to determine if there is a discrepancy in measured values of diluted exhaust flow. A propane check also serves as a batch-sampler verification to determine if there is a discrepancy in a batch sampling system that extracts a sample from a CVS, as described in 9.8.5.7. Using good engineering judgment and safe practices, this check may be performed using a gas other than propane, such as CO_2 or CO. A failed propane check might indicate one or more problems that may require corrective action, as follows:

   1) Incorrect analyser calibration. The FID analyser shall be re-calibrated, repaired, or replaced.

   2) Leak checks shall be performed on CVS tunnel, connections, fasteners, and HC sampling system according to 9.3.

   3) The verification for poor mixing shall be performed in accordance with 5.2.5.3.

   4) The hydrocarbon contamination verification in the sample system shall be performed as described in ISO 8178-4:2020, 8.3.1.

   5) Change in CVS calibration. An in-situ calibration of the CVS flow meter shall be performed as described in 9.8.

   6) Other problems with the CVS or sampling verification hardware or software. The CVS system, CVS verification hardware, and software shall be inspected for discrepancies.

b) A propane check uses either a reference mass or a reference flow rate of C_3H_8 as a tracer gas in a CVS. If a reference flow rate is used, any non-ideal gas behaviour of C_3H_8 in the reference flow meter shall be accounted for. See ISO 8178-4:2020, Annex H (molar based approach) or ISO 8178-4:2020, Clause 9 (mass based approach), which describe how to calibrate and use certain flow meters. No ideal gas assumption may be used in 9.8.5 and ISO 8178-4:2020, Annex H or Clause 9. The propane check compares the calculated mass of injected C_3H_8 using HC measurements and CVS flow rate measurements with the reference value.

9.8.5.2 Method of introducing a known amount of propane into the CVS system

The total accuracy of the CVS sampling system and analytical system shall be determined by introducing a known mass of a pollutant gas into the system while it is being operated in the normal manner. The pollutant is analysed, and the mass calculated according to ISO 8178-4:2020, Annex H or Clause 9. Either of the following two techniques shall be used.

a) Metering by means of a gravimetric technique shall be done as follows: A mass of a small cylinder filled with carbon monoxide or propane shall be determined with a precision of ±0,01 g. For about 5 min to 10 min, the CVS system shall be operated as in a normal exhaust emission test, while carbon monoxide or propane is injected into the system. The quantity of pure gas discharged shall be determined by means of differential weighing. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated.

b) Metering with a critical flow orifice shall be done as follows: A known quantity of pure gas (carbon monoxide or propane) shall be fed into the CVS system through a calibrated critical orifice. If the inlet pressure is high enough, the flow rate, which is adjusted by means of the critical flow orifice, is independent of the orifice outlet pressure (critical flow). The CVS system shall be operated as in a normal exhaust emission test for about 5 min to 10 min. A gas sample shall be analysed with the usual equipment (sampling bag or integrating method), and the mass of the gas calculated.

9.8.5.3 Preparation of the propane check

The propane check shall be prepared as follows:

a) If a reference mass of C_3H_8 is used instead of a reference flow rate, a cylinder charged with C_3H_8 shall be obtained. The reference cylinder's mass of C_3H_8 shall be determined within ±0,5 % of the amount of C_3H_8 that is expected to be used.

b) Appropriate flow rates shall be selected for the CVS and C_3H_8.

c) A C_3H_8 injection port shall be selected in the CVS. The port location shall be selected to be as close as practical to the location where engine exhaust is introduced into the CVS. The C_3H_8 cylinder shall be connected to the injection system.

d) The CVS shall be operated and stabilized.

e) Any heat exchangers in the sampling system shall be pre-heated or pre-cooled.

f) Heated and cooled components such as sample lines, filters, chillers, and pumps shall be allowed to stabilize at operating temperature.

g) If applicable, a vacuum side leak verification of the HC sampling system shall be performed as described in 9.3.

9.8.5.4 Preparation of the HC sampling system for the propane check

Vacuum side leak check verification of the HC sampling system may be performed according to g) of this subclause. If this procedure is used, the HC contamination procedure in ISO 8178-4:2020, 8.3.1 may be used. If the vacuum side leak check is not performed according to g), then the HC sampling system shall be zeroed, spanned, and verified for contamination, as follows:

a) The lowest HC analyser range that can measure the C_3H_8 concentration expected for the CVS and C_3H_8 flow rates shall be selected.

b) The HC analyser shall be zeroed using zero gas introduced at the analyser port.

c) The HC analyser shall be spanned using C_3H_8 span gas introduced at the analyser port.

d) Zero gas shall be overflowed at the HC probe or into a fitting between the HC probe and the transfer tube.

e) The stable HC concentration of the HC sampling system shall be measured as overflow zero gas flows. For batch HC measurement, the batch container (such as a bag) shall be filled and the HC overflow concentration measured.

f) If the overflow HC concentration exceeds 2 µmol/mol, the procedure may not be advanced until contamination is eliminated. The source of the contamination shall be determined and corrective action taken, such as cleaning the system or replacing contaminated portions.

g) When the overflow HC concentration does not exceed 2 µmol/mol, this value shall be recorded as x_{HCinit} and it shall be used to correct for HC contamination as described in ISO 8178-4:2020, Annex H (molar based approach) or ISO 8178-4:2020, Clause 9 (mass based approach).

9.8.5.5 Propane check performance

a) The propane check shall be performed as follows:

  1) For batch HC sampling, clean storage media, such as evacuated bags shall be connected.

  2) HC measurement instruments shall be operated according to the instrument manufacturer's instructions.

  3) If correction for dilution air background concentrations of HC is foreseen, background HC in the dilution air shall be measured and recorded.

  4) Any integrating devices shall be zeroed.

  5) Sampling shall begin and any flow integrators shall be started.

  6) C_3H_8 shall be released at the rate selected. If a reference flow rate of C_3H_8 is used, the integration of this flow rate shall be started.

  7) C_3H8 shall be continued to be released until at least enough C_3H_8 has been released to ensure accurate quantification of the reference C_3H_8 and the measured C_3H_8.

  8) The C_3H_8 cylinder shall be shut off and sampling shall continue until it has been accounted for time delays due to sample transport and analyser response.

  9) Sampling shall be stopped and any integrators shall be stopped.

b) In case the metering with a critical flow orifice is used, the following procedure may be used for the propane check as the alternative method of 9.8.5.5 a).

  1) For batch HC sampling, clean storage media, such as evacuated bags shall be connected.

  2) HC measurement instruments shall be operated according to the instrument manufacturer's instructions.

  3) If correction for dilution air background concentrations of HC is foreseen, background HC in the dilution air shall be measured and recorded.

  4) Any integrating devices shall be zeroed.

  5) The contents of the C_3H_8 reference cylinder shall be released at the rate selected.

  6) Sampling shall begin, and any flow integrators started after confirming that HC concentration is to be stable.

  7) The cylinder's contents shall be continued to be released until at least enough C_3H_8 has been released to ensure accurate quantification of the reference C_3H_8 and the measured C_3H_8.

8) Any integrators shall be stopped.

9) The C_3H_8 reference cylinder shall be shut off.

9.8.5.6 Evaluation of the propane check

Post-test procedure shall be performed as follows:

a) If batch sampling has been used, batch samples shall be analysed as soon as practical.

b) After analysing HC, contamination and background shall be corrected for.

c) Total C_3H_8 mass based on the CVS and HC data shall be calculated as described in ISO 8178-4:2020, Annex H or Clause 9, using the molar mass of C_3H_8, M_{C3H8}, instead the effective molar mass of HC, M_{HC}.

d) If a reference mass (gravimetric technique) is used, the cylinder's propane mass shall be determined within ±0,5 % and the C_3H_8 reference mass shall be determined by subtracting the empty cylinder propane mass from the full cylinder propane mass. If a critical flow orifice (metering with a critical flow orifice) is used, the propane mass shall be determined as flow rate multiplied by the test time.

e) The reference C_3H_8 mass shall be subtracted from the calculated mass. If this difference is within ±3,0 % of the reference mass, the CVS passes this verification.

9.8.5.7 PM secondary dilution system verification

When the propane check is to be repeated to verify the PM secondary dilution system, the following procedure from a) to d) shall be used for this verification:

a) The HC sampling system shall be configured to extract a sample near the location of the batch sampler's storage media (such as a PM filter). If the absolute pressure at this location is too low to extract an HC sample, HC may be sampled from the batch sampler pump's exhaust. Caution shall be used when sampling from pump exhaust because an otherwise acceptable pump leak downstream of a batch sampler flow meter will cause a false failure of the propane check.

b) The propane check shall be repeated as described in this subclause, but HC shall be sampled from the batch sampler.

c) C_3H_8 mass shall be calculated, taking into account any secondary dilution from the batch sample.

d) The reference C_3H_8 mass shall be subtracted from the calculated mass. If this difference is within ±5 % of the reference mass, the batch sampler passes this verification. If not, corrective action shall be taken.

9.8.5.8 Sample dryer verification

If a humidity sensor for continuous monitoring of dew point at the sample dryer outlet is used this check does not apply, as long as it is ensured that the dryer outlet humidity is below the minimum values used for quench, interference, and compensation checks.

a) If a sample dryer is used as allowed in 5.2.2.3.1 to remove water from the sample gas, the performance shall be verified upon installation, after major maintenance, for thermal chiller. For osmotic membrane dryers, the performance shall be verified upon installation, after major maintenance, and within 35 days of testing.

b) Water can inhibit an analyser's ability to properly measure the exhaust component of interest and thus is sometimes removed before the sample gas reaches the analyser. For example water can negatively interfere with a CLD's NOx response through collisional quenching and can positively interfere with an NDIR analyser by causing a response similar to CO.

c) The sample dryer shall meet the specifications as determined in 5.2.2.3.1 for dew point, T_{dew}, and absolute pressure, p_{total}, downstream of the osmotic-membrane dryer or thermal chiller.

d) The following sample dryer verification procedure method shall be used to determine sample dryer performance, or good engineering judgment shall be used to develop a different protocol:

   1) PTFE or stainless steel tubing shall be used to make necessary connections.

   2) N_2 or purified air shall be humidified by bubbling it through distilled water in a sealed vessel that humidifies the gas to the highest sample dew point that is estimated during emission sampling.

   3) The humidified gas shall be introduced upstream of the sample dryer.

   4) The humidified gas temperature downstream of the vessel shall be maintained at least 5 °C above its dew point.

   5) The humidified gas dew point, T_{dew}, and pressure, p_{total}, shall be measured as close as possible to the inlet of the sample dryer to verify that the dew point is the highest that was estimated during emission sampling.

   6) The humidified gas dew point, T_{dew}, and pressure, p_{total}, shall be measured as close as possible to the outlet of the sample dryer.

   7) The sample dryer meets the verification if the result of d) 6) of this subclause is less than the dew point corresponding to the sample dryer specifications as determined in 5.2.2.3.1 plus 2 °C or if the mol fraction from d) 6) is less than the corresponding sample dryer specifications plus 0,002 mol/mol or 0,2 Vol %. Note for this verification, sample dew point is expressed in absolute temperature, Kelvin.

9.8.6 Periodic calibration of the partial flow PM and associated raw exhaust gas measurement systems

9.8.6.1 Specifications for differential flow measurement

For partial flow dilution systems to extract a proportional raw exhaust sample, the accuracy of the sample flow q_{mp} is of special concern, if not measured directly, but determined by differential flow measurement:

$$q_{mp} = q_{m\text{dew}} - q_{m\text{dw}} \tag{25}$$

where

q_{mp} is sample mass flow rate of exhaust gas into partial flow dilution system;

$q_{m\text{dw}}$ is dilution air mass flow rate (on wet basis);

$q_{m\text{dew}}$ is diluted exhaust gas mass flow rate on wet basis.

In this case, the maximum error of the difference shall be such that the accuracy of q_{mp} is within ±5 % when the dilution ratio is less than 15. It can be calculated by taking root-mean-square of the errors of each instrument.

Acceptable accuracies of q_{mp} can be obtained by either of the following methods:

a) The absolute accuracies of $q_{m\text{dew}}$ and $q_{m\text{dw}}$ are ±0,2 % which guarantees an accuracy of q_{mp} of ≤5 % at a dilution ratio of 15. However, greater errors will occur at higher dilution ratios.

b) Calibration of $q_{m\text{dw}}$ relative to $q_{m\text{dew}}$ is carried out such that the same accuracies for q_{mp} as in a) are obtained. For details see 9.8.6.2.

c) The accuracy of q_{mp} is determined indirectly from the accuracy of the dilution ratio as determined by a tracer gas, e.g. CO_2. Accuracies equivalent to method a) for q_{mp} are required.

d) The absolute accuracy of q_{mdew} and q_{mdw} is within ±2 % of full scale, the maximum error of the difference between q_{mdew} and q_{mdw} is within 0,2 % and the linearity error is within ±0,2 % of the highest q_{mdew} observed during the test.

9.8.6.2 Calibration of differential flow measurement

The partial flow dilution system to extract a proportional raw exhaust sample shall be periodically calibrated with an accurate flow meter traceable to international and/or national standards. The flow meter or the flow measurement instrumentation shall be calibrated in one of the following procedures, such that the probe flow q_{mp} into the tunnel shall fulfil the accuracy requirements of 9.8.6.1.

a) The flow meter for q_{mdw} shall be connected in series to the flow meter for q_{mdew}, the difference between the two flow meters shall be calibrated for at least 5 set points with flow values equally spaced between the lowest q_{mdw} value used during the test and the value of q_{mdew} used during the test. The dilution tunnel may be bypassed.

b) A calibrated flow device shall be connected in series to the flowmeter for q_{mdew} and the accuracy shall be checked for the value used for the test. The calibrated flow device shall be connected in series to the flow meter for q_{mdw}, and the accuracy shall be checked for at least 5 settings corresponding to dilution ratio between 3 and 15, relative to q_{mdew} used during the test.

c) The transfer tube TT (see Figure 8) shall be disconnected from the exhaust and a calibrated flow measuring device with a suitable range to measure q_{mp} shall be connected to the transfer tube. q_{mdew} shall be set to the value used during the test, and q_{mdw} shall be sequentially set to at least 5 values corresponding to dilution ratios between 3 and 15. Alternatively, a special calibration flow path may be provided, in which the tunnel is bypassed, but the total and dilution air flow is passed through the corresponding meters as in the actual test.

d) A tracer gas, shall be fed into the exhaust transfer tube TL. This tracer gas may be a component of the exhaust gas, like CO_2 or NO_x. After dilution in the tunnel the tracer gas component shall be measured. This shall be carried out for 5 dilution ratios between 3 and 15. The accuracy of the sample flow shall be determined from the dilution ratio r_d:

$$q_{mp} = \frac{q_{mdew}}{r_d} \tag{26}$$

The accuracies of the gas analysers shall be taken into account to guarantee the accuracy of q_{mp}.

9.8.6.3 Special requirements for differential flow measurement

A carbon flow check using actual exhaust is strongly recommended for detecting measurement and control problems and verifying the proper operation of the partial flow system. The carbon flow check should be run at least each time a new engine is installed, or something significant is changed in the test cell configuration.

The engine shall be operated at peak torque load and speed or any other steady state mode that produces 5 % or more of CO_2. The partial flow sampling system shall be operated with a dilution factor of about 15 to 1.

If a carbon flow check is conducted, the procedure given in Annex C shall be applied. The carbon flow rates shall be calculated according to equations of Annex C. All carbon flow rates shall agree to within 5 %.

9.8.6.3.1 Pre-test check

A pre-test check shall be performed within 2 hours before the test run in the following way.

The accuracy of the flow meters shall be checked by the same method as used for calibration (see 9.8.6.2) for at least two points, including flow values of q_{mdw} that correspond to dilution ratios between 5 and 15 for the q_{mdew} value used during the test.

If it can be demonstrated by records of the calibration procedure under 9.8.6.2 that the flow meter calibration is stable over a longer period of time, the pre-test check may be omitted.

9.8.6.3.2 Determination of the transformation time

The system settings for the transformation time evaluation shall be the same as during measurement of the test run. The transformation time, defined in Figure 1, shall be determined by the following method:

An independent reference flowmeter with a measurement range appropriate for the probe flow shall be put in series with and closely coupled to the probe. This flowmeter shall have a transformation time of less than 100 ms for the flow step size used in the response time measurement, with flow restriction sufficiently low as to not affect the dynamic performance of the partial flow dilution system according to good engineering judgment. A step change shall be introduced to the exhaust flow (or air flow if exhaust flow is calculated) input of the partial flow dilution system, from a low flow to at least 90 % of full scale. The trigger for the step change shall be the same one used to start the look-ahead control in actual testing. The exhaust flow step stimulus and the flowmeter response shall be recorded at a sample rate of at least 10 Hz.

From this data, the transformation time shall be determined for the partial flow dilution system, which is the time from the initiation of the step stimulus to the 50 % point of the flowmeter response. In a similar manner, the transformation times of the q_{mp} signal (i.e. sample flow of exhaust gas into partial flow dilution system) and of the $q_{mew,i}$ signal (i.e. the exhaust gas mass flow rate on wet basis supplied by the exhaust flow meter) shall be determined. These signals are used in the regression checks performed after each test (see ISO 8178-4:2020, 8.2.1.2).

The calculation shall be repeated for at least 5 rise and fall stimuli, and the results shall be averaged. The internal transformation time (<100 ms) of the reference flowmeter shall be subtracted from this value. In the case that the system in accordance with ISO 8178-4:2020, 8.2.1.2. requires the "look-ahead" method, this is the "look-ahead" value of the partial flow dilution system to be applied in accordance with ISO 8178-4:2020, 8.2.1.2.

9.9 Calibration of the dynamometer

The engine manufacturer shall apply internal quality procedures traceable to recognised national or international standards, e.g. by laboratories certified according to ISO/IEC 17025. Otherwise the following procedures apply.

9.9.1 Torque calibration

9.9.1.1 Scope and frequency

All torque-measurement systems including dynamometer torque measurement transducers and systems shall be calibrated upon initial installation and after major maintenance using, among others, reference force or lever-arm length coupled with dead weight. Good engineering judgment shall be used to repeat the calibration. The torque transducer manufacturer's instructions shall be followed for linearizing the torque sensor's output. Other calibration methods are permitted.

9.9.1.2 Dead-weight calibration

This technique applies a known force by hanging known weights at a known distance along a lever arm. It shall be made sure that the weights' lever arm is perpendicular to gravity (i.e., horizontal) and perpendicular to the dynamometer's rotational axis. At least six calibration-weight combinations shall be applied for each applicable torque-measuring range, spacing the weight quantities about equally over the range. The dynamometer shall be oscillated or rotated during calibration to reduce frictional static hysteresis. Each weight's force shall be determined by multiplying its internationally-traceable mass by the local acceleration of Earth's gravity in accordance with Annex A.

9.9.1.3 Strain gage or proving ring calibration

This technique applies force either by hanging weights on a lever arm (these weights and their lever arm length are not used as part of the reference torque determination) or by operating the dynamometer at different torques. At least six force combinations shall be applied for each applicable torque-measuring range, spacing the force quantities about equally over the range. The dynamometer shall be oscillated or rotated during calibration to reduce frictional static hysteresis. In this case, the reference torque is determined by multiplying the force output from the reference meter (such as a strain gage or proving ring) by its effective lever-arm length, which is measured from the point where the force measurement is made to the dynamometer's rotational axis. It shall be made sure that this length is measured perpendicular to the reference meter's measurement axis and perpendicular to the dynamometer's rotational axis.

9.10 Calibration of temperature, pressure and dew point sensors

The engine manufacturer shall apply internal quality procedures traceable to recognised national or international standards, e.g. by laboratories certified according to ISO/IEC 17025. Otherwise the following procedures apply.

Instruments shall be calibrated for measuring pressure, temperature, and dew point upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

For temperature measurement systems with thermocouple, RTD, or thermistor sensors, the calibration of the system shall be performed as described in 9.1.4.4 for linearity verification.

9.11 Flow-related measurements

9.11.1 Fuel flow calibration

Fuel flow meters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration.

9.11.2 Intake air flow calibration

Intake air flow meters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration. A calibration subsonic venturi, ultrasonic flow meter or laminar flow element should be used. Calibration reference quantities should be used, that are internationally-traceable within 0,5 % uncertainty.

If a subsonic venturi or ultrasonic flow meter is used for intake flow measurement, its calibration should be performed as described in 9.8.

9.11.3 Exhaust flow calibration

Exhaust flow meters shall be calibrated upon initial installation. The instrument manufacturer's instructions shall be followed and good engineering judgment shall be used to repeat the calibration. A calibration subsonic venturi or ultrasonic flow meter should be used; exhaust temperatures should be simulated by incorporating a heat exchanger between the calibration meter and the exhaust-flow meter. If it can be demonstrated that the flow meter to be calibrated is insensitive to exhaust temperatures, other reference meters such as laminar flow elements may be used, which are not commonly designed to withstand typical raw exhaust temperatures. Calibration reference quantities should be used, that are internationally-traceable within 0,5 % uncertainty.

If a subsonic venturi or ultrasonic flow meter is used for raw exhaust flow measurement, it should be calibrated as described in 9.8.

Annex A
(normative)

1980 international gravity formula

The acceleration of Earth's gravity, a_g, varies depending on the location and a_g is calculated for a respective latitude, as follows:

$$a_g = 9{,}780\,326\,771\,5 \begin{bmatrix} 1 + 5{,}279\,041\,4 \times 10^{-3} \sin^2\theta + 2{,}327\,18 \times 10^{-5} \sin^4\theta + \\ 1{,}262 \times 10^{-7} \sin^6\theta + 7 \times 10^{-10} \sin^8\theta \end{bmatrix} \quad \text{(A.1)}$$

where θ is the degrees north or south latitude.